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IMPACT OF A NEW GRAVITY WAVE DRAG SCHEME AND OROGRAPHIC ROUGHNESS IN THE UNIFIED MODEL. III . REVISED SCHEMES AND SECOND PARALLEL SUITE TRIAL FOR GLOBAL AND LIMITED AREA MODELS

by

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JAN 1995

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1. INTRODUCTION

A new gravity wave drag scheme and inclusion of a representation of orographic roughness have been developed for the unified model (**Technical Report 127** ,Milton et al, 1994). Following an assessment of the results of the first parallel suite trial (**Technical Report 128** ,Wilson and Hammon, 1994) the schemes have been revised to address some of the disadvantages. The revisions are described in section 2.

This technical report contains the results and assessment of tests of the revised schemes with the global model and a second parallel suite trial. For the latter, the global forecast and limited area model versions were run in parallel to the operational suite from 02/12/94 to 15/12/94. (A longer period would have been desirable to reduce the effects of unrepresentative sampling, particularly for the T+120 verification, but other demands on the parallel suite did not permit this.) A fully independent assimilation cycle was maintained for the parallel global model and forecasts to T+120 were made once per day from the 12 UTC main analysis time. The limited area model 4-cycle assimilation (15,18,21,00 UTC) was intermittently started from the 12 UTC analysis and forecasts to T+36 were made once per day from its own 00 UTC analysis. The operational verification packages were included to give comparable statistics from the parallel and operational suites.

The parallel suite trial also included the additional corrections for the elimination of superadiabatic profiles (see **Technical Report 125**, Wilson et al, 1994), which were not implemented operationally until 13/12/94. In previous tests these were generally found to have a very small or neutral impact on verification, although they do impact on convecive precipitation and low cloud (see section 5). However the longer timestep for physics, also

implemented operationally on 13/12/94 was not included in the parallel runs.

Conclusions are given at the end of each of sections 4,5,6 and 7, with the final summary in section 8.

2. Revised Parametrizations

A number of revisions have been made to the first formulation of the new gravity wave drag and orographic roughness (described in Milton et al.1994, **Technical Report 127** hereafter referred to as M94). These include:

New Gravity Wave Drag Scheme
(i) The gravity wave stress removed below the hydraulic jump height (H_o) in the 'High Drag State' has been changed from 4/5 to 2/3 of the surface gravity wave stress.

(ii) The tuneable constant K_Lee has been increased from 1.5E05 to 1.8E05.

Orographic Roughness
(i) A new ancillary file of the silhouette area of orography, A/S, has been derived. Currently, A/S is derived from the standard deviation of orography ($\sigma^{1/2}$) using the parametrization proposed by R.Smith (see M94). Values of A/S have also been calculated directly from a high resolution (30 second) orography dataset over Europe using the formula of Mason (1985),

$$\frac{A}{S} = \frac{\Sigma\, H(\Delta h)\,\Delta h}{L}$$

where Δh is the change in height between adjacent points, L the horizontal distance over which the measurement is made, and $H(\Delta h)$ is unity if $\Delta h>0$ and zero otherwise. Comparison of the values derived from the Mason formula and those from the Smith parametrization show that the parametrization gives A/S (and hence roughness lengths) which are too high. A linear relationship between the standard deviation of orography from the 10 minute orography dataset and this new A/S is then derived as

$$\frac{A}{S} = a\,\sigma^{\frac{1}{2}}$$

Where a is defined for each model resolution (a=0.000167862 for global operational resolution). Values of A/S can now be calculated from the standard deviation of orography. These new values of A/S are not allowed to exceed 0.2.

(ii) An upper limit of 1000 metres has been placed upon the value of the blending height. This is a further attempt to prevent excessive orographic roughness lengths appearing in the

parametrization, as the blending height appears in the equation for the effective roughness length for momentum (Mason, 1985).

(iii) In the previous formulation z_{oh} was set to be $0.1*z_{om}$, where z_{om} is the background or vegetative roughness. This was changed back to the relationship used operationally in which $z_{oh} = z_{om}$.

(iv) A reformulation of the scalar surface transfer coefficient (C_H) is introduced. The first parallel trial used a formulation based upon an effective roughness length for scalars. This was defined to leave C_H at its value without orographic drag effects. However the flux formulae involve a term $C_H v_1$, and since v_1 has decreased then the surface flux is also decreased. Recent work in APR (N.Wood, personal communication) has suggested that C_H is formulated using the usual Monin-Obhukov theory for scalar profiles in the surface layer but with the 'scaling' or 'friction' velocity based upon shear stress only (i.e. not including orographic effects). This change was made for the second parallel trial

3. Case Studies and One Week Tests.

The set of 5 case studies run from analyses on the 1st, 5th, 10th ,15th and 20th of December 1993 (M94), have been re-run with the reformulation of the new gravity wave drag and orographic roughness schemes. In addition the one week trials including full data assimilation has also been run for the period 7/1/94 to 13/1/94 and 11/08/93 to 17/08/93. (These latter tests also included the superadiabat corrections and so are stricly comparable to the second parallel suite trial.) This section contrasts the performance of the reformulated parametrizations in both case studies and one week trials against the operational forecasts and previous formulation. The experiments are referred to in the remainder of the text as

OP	Operational
ROGW1	Orographic Roughness/GWD as formulated for the 1st parallel trial.
ROGW2	Orographic Roughness/New GWD reformulated for the 2nd parallel trial.

3.1 Impact on the Large-Scale Circulation.

In this section all diagnostics shown are averages over the 5 case studies run from December 1993.

(i) Zonally averaged U,V, and Temperature.

The systematic error (SE) in the zonally averaged zonal wind at T+120 in OP (**Fig. 3.1(a)**) shows excessive westerlies in mid-latitudes of both hemispheres, and easterly SE in the tropics and over Antarctica. In ROGW2 there is a reduction in the mid-latitude westerly bias in the Northern Hemisphere (NH) both in the boundary layer and at jet level (**Fig.3.1(b)**). However, in the Tropics the easterly bias at 10N-20N is increased compared to OP. This is also a problem in ROGW1 and has not improved with the reformulation. The impact of the new parametrizations is shown in the difference, ROGW2-OP (**Fig3.1(c)**), which is in the opposite sense to the operational SE (**Fig.3.1(a)**) and hence acts to reduce the errors at most latitudes.

A similar beneficial impact is obtained with ROGW1 (M94). Differences between ROGW2 and ROGW1 (**FIG 3.1(d)**) show that;

(i) ROGW2 is more westerly at 50N-60N than ROGW1.
(ii) Over Antarctica ROGW2 is more easterly than ROGW1.

These differences are a consequence of the reduction in parametrized sub-gridscale form drag resulting from the smaller orographic roughnesses applied in ROGW2. The first difference represents a marginal improvement in ROGW2 over ROGW1 as in M94 it was noted that ROGW1 tends to increase the easterly bias at 50N-60N compared to OP (see M94 - Fig. 5(d)), suggesting that too much drag may have been applied to the model. In M94 it was also shown that ROGW1 significantly reduced the easterly bias over Antarctica compared to OP. The increased easterlies in ROGW2 relative to ROGW1 over Antarctica show that the reduction in the easterly bias is not as large in ROGW2 as in ROGW1. However, ROGW2 is still an improvement over OP. Further work is required in assessing the role of subgridscale orographic drag on the Antarctic climate.

For the meridional wind we have an increase in the mean meridional circulation in OP at T+120 (**FIG. 3.2(b)**), with overactive Hadley and Ferrel cells and excessive equatorward flow off the Antarctic continent at 70S. The impact of the new parametrizations in ROGW2 is to generate an indirect circulation at 50N-60N relative to OP(**FIG 3.2(c)**). Such a circulation can be anticipated from the Kuo-Eliassen diagnostic equation for the mean meridional circulation (Grotjahn, 1993) and is consistent with applying more drag in the boundary layer. Similar results are found for ROGW1 in M94. The largest difference in the meridional wind between ROGW2 and ROGW1 is over Antarctica (**FIG. 3.2(d)**) where the equatorward meridional flow at 70S is larger in ROGW2 due to the reduced orographic roughness. As found for the zonal wind we note that ROGW1 also provides the better simulation over Antarctica in terms of the meridional wind.

In ROGW1 the NH upper troposphere cools by -0.5K to -1.0K relative to OP (**FIG 3.3 (b)**) increasing the model cold bias (**FIG. 3.3(a)**). There is also a warming of the near surface in NH mid-latitudes compared to OP (**FIG 3.3(b)**). The difference in zonally averaged temperature, ROGW2-ROGW1, shows that the upper tropospheric cooling and low level warming which occur relative to OP, have been reduced in ROGW2, but not completely removed. The warmer upper troposphere in ROGW2 relative to ROGW1 is a consequence of more gravity wave drag being applied in the stratosphere in ROGW2 (see section 3.2). The application of more upper level drag leads to a compensating direct meridional circulation which transports more heat polewards and warms the pole (see Palmer et al., 1986). The decrease in the low level warming in ROGW2 may be a consequence of either the change to the scalar transfer coefficient or the increase in z_{oh}.

(ii) Mean Sea Level Pressure.
The zonally averaged profile of mean sea level pressure (MSLP) at T+120 shows that both ROGW1 and ROGW2 are marked improvements over OP (**FIG. 3.4**). ROGW1 is a closer fit

to the analyses in the region of the mid-latitude trough at 60N, whereas polewards of this ROGW2 is closer to the analyses and ROGW1 has too high pressure. Both ROGW1 and ROGW2 improve the subtropical highs and the Antarctic circumpolar trough. However in the tropics OP is the better forecast with both ROGW1 and ROGW2 having too low pressure. Over Antarctica pressure is too high in all of the forecasts.

The geographical distribution of the response to the new parametrizations is shown in **FIGURE 3.5**. For the NH the difference ROGW2-OP (**FIG. 3.5(a)**) shows that the new parametrizations raise the pressure north of 40N. In ROGW1 the increase of pressure is more intense as shown by the difference ROGW2-ROGW1 (**FIG 3.5(b)**). This is particularly true over Europe where the pressure in ROGW2 is 4mb lower than in ROGW1, but still up to 6mb higher than OP (**FIG. 3.5(a)**). In the Southern Hemisphere (SH) the main impact in ROGW2 is an increase in pressure relative to OP in the circumpolar trough with a maximum response downstream of the Andes and the Antarctic Peninsula (**FIG. 3.5(c)**). Compared to ROGW1 we note that ROGW2 has lower pressure in the Antarctic trough and higher pressure over Antarctica (**FIG. 3.5(d)**). This difference is consistent with ROGW2 having larger (erroneous) meridional flow off the Antarctic continent than ROGW1, although ROGW2 is still an improvement over OP forecasts in this region.

Finally we look at the T+120 SE in MSLP. In the NH the OP forecasts have lower pressures than analysed over much of the hemisphere (**FIG. 3.6(b)**). Both ROGW1 and ROGW2 have reduced SE compared to OP. The tendency for ROGW1 to increase the positive errors has been reduced in ROGW2 particularly over Europe, and this is borne out by the verification of MSLP in the second parallel suite (see section 4). In the SH we see improvements in the circumpolar trough in ROGW1 and ROGW2, most notably in the vicinity of the Falkland Islands (**FIG. 3.7**).

3.2 MOMENTUM BALANCE

This section briefly discusses the changes to the parametrized forcing in the Unified Model when the new formulation in ROGW2 is used in place of that in ROGW1. A more general discussion of the impact of including orographic roughness and low level gravity wave breaking effects on the momentum budget is given in M94 and the general conclusions presented there still hold for the reformulated parametrizations in ROGW2.

The zonally averaged acceleration to the zonal wind provided by the boundary layer turbulent mixing scheme is shown in **FIGURE 3.8**. Both ROGW1 and ROGW2 provide an easterly drag on the westerlies in mid-latitudes and a westerly drag upon the easterly trade winds in the Tropics. The difference between ROGW2 and ROGW1 (**FIG. 3.8(c)**) shows reductions in the drag in ROGW2 between 30N-60N and over the edge of Antarctica at 70S as a consequence of reducing the orographic roughness.

The acceleration due to the gravity wave drag scheme is similar in ROGW1 (**FIG. 3.9(a)**) and ROGW2 (**FIG 3.9(b)**), with maxima in the boundary layer and stratosphere in the NH. The

difference between ROGW2 and ROGW1 (**FIG. 3.9(c)**) shows that ROGW2 applies more drag in both the boundary layer and stratosphere. This overall increase in gravity wave drag is due to the reduction in the orographic roughness applied to ROGW2. This allows greater low level winds in the model over orography which feeds into the gravity wave drag scheme through the expression for the surface gravity wave drag. The increased drag in the stratosphere in ROGW2 is also partly a consequence of reducing the fraction of stress removed below the hydraulic jump height during high drag states from 4/5 to 2/3. The increased gravity wave drag in the boundary layer partially compensates for reductions in surface drag due decreasing orographic roughnesses in ROGW2.

In summary the total parametrised drag (not shown) in ROGW2 is reduced in the boundary layer and increased in the stratosphere relative to ROGW1.

3.3 OBJECTIVE VERIFICATION AGAINST OBSERVATIONS.

In this section we present objective verification scores from the January and August one week trials of OP and ROGW2 run with full assimilation. In general the results are very similar to those found in ROGW1, and we restrict ourselves to discussion of the RMS vector wind error and temperature bias scores at T+72 for 3 latitude bands; the Northern Hemisphere (NH) extratropics (90N-30N), Tropics (30N-30S), and Southern Hemisphere (SH) extratropics (30S-90S). The results are summarised below.

(i) *January.*

In NH extratropics there is a reduction in RMS vector wind error in ROGW2 compared to OP in the lower troposphere and stratosphere, with smaller improvements at the jet maxima (**FIG. 3.10(a)**). In the Tropics ROGW2 is an improvement over OP in the lowest 3 model layers but shows a degradation in the mid and upper troposphere (**FIG. 3.10(b)**). This was also the case for ROGW1 and has not improved with the reformulation. The SH extratropics is improved in ROGW2 compared to OP in model layers 1-4 (**FIG 3.10(c)**).

For temperature in the NH extratropics we see a reduction in the low level cold bias in ROGW2 compared to OP (**FIG. 3.11(a)**). This is different to ROGW1 where the low level cold bias in OP became a warm bias (Milton et al., 1994). Above model level 8 the cold bias is made worse in ROGW2 (**FIG. 3.11(a)**), although this additional cooling in ROGW2 is smaller than that found for ROGW1. In the Tropics we see a similar reduction of cold bias in the lower troposphere in ROGW 2 compared to OP (**FIG 3.11(b)**). For the SH extratropics a low level warm bias in OP is made worse in ROGW2 (**FIG 3.11(c)**). Again, a similar but more extreme degradation was found for ROGW1.

(ii) *August*

The August results are almost identical to those found in ROGW1. There are reductions in RMS vector wind error at all latitudes in the lower troposphere and at jet level in ROGW2,

and in the SH extratropics these reductions appear at all model levels up to level 12 (**FIG. 3.12(b)**).

Finally, the impact on the temperature bias for NH extratropics is similar to that in January with the low level cold bias reduced and the upper troposphere cold bias made slightly worse (**FIG 3.13(a)**). The SH extratropics also show a reduction in low level cold bias in ROGW2 compared to OP (**FIG. 3.13(c)**), but the Tropics show an increased low level warm bias.

In general we see a positive benefit from introducing the new parametrizations of gravity wave drag and orographic roughness, although the impact of the changes has been reduced compared to the formulation used in the first parallel trial (Milton et al, 1994; Wilson and Hammon, 1994).

4. OBJECTIVE VERIFICATION - GLOBAL MODEL

The analyses and forecasts were verified against observations (sondes and synops) for the period 02/12/94 to 15/12/94. Verification was also performed against analyses, each suite was verified against its own analyses for the same period. Time-mean results will mostly be discussed here . Results for forecast times T+0, T+24, T+48, T+72, T+120 and for areas "2", N. Hemisphere to 30N ("200"), Tropics 30N-30S ("300") and S. Hemisphere from 30S ("400") will be given.

4. 1 RMS ERRORS -OVERALL SUMMARY

TABLE 4.1 summarises the objective scores for the N. Atlantic region (area 2) and extratropical N. Hemisphere. It shows the percentage changes in rms errors for heights, temperatures , vector winds (8 levels each) , relative humidity (3 levels) and 3 surface fields. A negative value shows the trial to be an improvement. Column and surface-means are also shown.

Height errors show general improvements at T+24, T+48 and T+72, with ~7% improvements at lower levels and up to 11% improvements at 100hPa. At T+120 the results for the trial are still better at 500hPa and below, although they are smaller than for the earlier time periods, and the errors are generally larger between 300 and 200hPa. The smaller impact of the trial package at T+120 contrasts with the previous parallel suite test where the largest improvements were found at this forecast range (see **Technical Report 128**). We should be cautious of drawing too many conclusions from this however since the present trial is much shorter and the sample contains only 9 forecasts verifying at T+120. The synoptic variability could also be quite different from the earlier trial period (31/10/94-14/11/94).

There are similarly large improvements in temperature scores at the shorter time ranges with largest changes at T+48, when the mean improvement is ~4%,; the impact is slightly reduced at T+72 and is again smaller at T+120, although the worse scores for the trial are now at lower levels (500hPa and below). Winds are mostly better, with substantially smaller errors near the surface at 850hPa and at jet levels . The general pattern of results noted for heights

%RMS CHANGE (TRIAL-OPERATIONAL) PERIOD 03/12/94-15/12/94											
VERIFICATION AGAINST OBSERVATIONS											
	T+0	T+24	T+48	T+72	T+120		T+0	T+24	T+48	T+72	T+120
AREA	2					AREA	200, NH to 30N				
HEIGHTS						HEIGHTS					
850	0.7	-4.6	-8.5	-7.4	-6.8	850	1.8	-7.0	-7.5	-5.3	-2.4
700	0.0	-1.1	-4.8	-4.7	-5.6	700	2.5	-3.6	-6.7	-5.1	-1.9
500	-0.9	-1.7	-5.0	-2.6	-2.8	500	0.6	-1.7	-6.0	-4.0	-0.2
300	-1.2	-4.4	-5.7	-3.0	3.1	300	-0.4	-4.2	-6.3	-4.1	2.3
250	-1.1	-4.7	-5.2	-2.5	4.3	250	-0.2	-3.8	-4.4	-3.5	2.9
200	-0.4	-4.9	-5.2	-3.3	4.4	200	-0.6	-3.4	-4.0	-3.5	2.5
100	-1.1	-8.8	-11.3	-10.5	-0.3	100	-0.5	-5.7	-9.9	-10.7	-4.9
50	0.1	-1.7	-3.8	-5.7	1.1	50	-0.3	-4.7	-8.3	-8.8	-3.9
Mean	-0.5	-4.0	-6.2	-5.0	-0.3	Mean	0.4	-4.3	-6.6	-5.6	-0.7
TEMPERATURES						TEMPERATURES					
850	-2.1	-3.3	-3.6	-3.6	0.3	850	-0.9	-3.0	-2.6	0.1	2.8
700	0.7	-3.1	-7.2	-2.8	-2.5	700	-0.5	-2.2	-2.5	-0.2	0.8
500	-0.9	-0.1	-4.3	-2.0	6.0	500	-1.7	-1.6	-2.2	-0.2	3.1
300	0.0	-1.1	-4.3	-1.1	1.0	300	-1.6	-3.9	-3.6	-1.2	-1.5
250	-1.1	-4.4	-4.5	-3.9	-5.5	250	-0.4	-5.5	-5.3	-4.4	-3.3
200	0.0	1.1	-4.3	-4.1	-7.9	200	-1.3	-3.0	-6.2	-5.8	-5.8
100	-0.5	0.0	-2.0	-3.3	-5.2	100	-0.5	-2.4	-4.3	-4.6	-2.9
50	0.0	-2.4	-3.0	-4.7	-0.9	50	0.3	-3.7	-5.4	-6.7	-7.1
Mean	-0.5	-1.7	-4.1	-3.2	-1.8	Mean	-0.8	-3.2	-4.0	-2.9	-1.7
WINDS						WINDS					
850	-0.1	-2.9	-3.7	-2.7	-5.5	850	-0.6	-6.0	-6.4	-4.1	-4.1
700	-0.7	-1.3	-1.2	-1.9	-4.1	700	-1.0	-3.0	-3.6	-3.3	-3.5
500	-0.1	-0.3	-0.8	-1.0	-3.7	500	-0.5	-1.4	-2.5	-1.3	-2.2
400	0.0	-1.4	-1.4	-1.7	-0.9	400	0.0	-1.2	-2.1	-1.7	0.3
300	-0.8	-1.8	-2.4	-2.2	2.2	300	-0.7	-0.9	-2.2	-1.6	2.5
250	-0.2	-1.1	-2.8	-3.8	1.7	250	-0.3	-1.2	-2.6	-2.2	2.4
200	0.1	-1.2	-4.8	-7.9	2.9	200	0.2	-2.2	-2.0	-3.5	2.9
100	-0.8	-6.8	-12.6	-14.7	-0.9	100	-1.5	-4.2	-5.7	-3.5	-1.1
Mean	-0.3	-2.1	-3.7	-4.5	-1.0	Mean	-0.5	-2.5	-3.4	-2.6	-0.4
RH						RH					
850	0.4	-1.7	-2.8	-3.1	-1.2	850	-2.0	-1.8	-2.0	-2.8	-2.3
700	-0.1	0.5	0.3	-2.1	1.7	700	-0.9	-0.3	-1.5	-1.9	-0.9
500	-0.5	-0.2	-0.4	-2.7	-3.2	500	-1.0	-0.6	-0.5	-1.7	-1.1
Mean	-0.1	-0.5	-1.0	-2.6	-0.9	Mean	-1.3	-0.9	-1.3	-2.1	-1.4
SURF						SURF					
-pmsl	-0.9	-4.7	-7.8	-4.1	-7.5	-pmsl	0.2	-8.2	-7.6	-5.3	-5.4
-temp	-2.4	-1.7	-0.9	-1.0	-1.8	-temp	-2.1	-4.2	-4.7	-3.7	-2.1
-wind	0.2	-2.2	-2.9	-2.6	-5.0	-wind	1.0	-2.3	-3.4	-3.0	-3.5
Mean	-1.0	-2.9	-3.9	-2.6	-4.8	Mean	-0.3	-4.9	-5.2	-4.0	-3.7
Mean all	-0.5	-2.4	-4.2	-3.9	-1.4	Mean all	-0.4	-3.2	-4.4	-3.6	-1.3

TABLE 4.1

and temperatures is again found, with large improvements up to T+72 and then a weaker, more mixed response at T+120. The upper levels at 200 and 100hPa are improved at all forecast times up to T+120, by ~2-8% and 5-15% respectively. This reflects the smaller gravity wave drag in the stratosphere noticed in earlier tests and the first parallel suite trial: this is an area which the modifications were aimed to improve since the gravity wave drag was too strong here due to insufficient gravity wave stress being absorbed at lower levels (see Technical Report 127). Relative humidities are also mostly better or equal to the operational.

Rms errors of surface pressure are greatly improved by between 4 and 8%, including at T+120. Scores for surface temperatures and winds are also much better for all forecast (and analysis times for temperatures). However the improvements are generally smaller than the previous trial, reflecting the smaller effect of orographic roughness and the larger heat and moisture transport.

Overall there is a significant reduction in rms errors for most parameters. Taking changes greater than 1%, the number of scores from **TABLE 4.1** for which the trial was better are given in **TABLE 4.3**.

TABLE 4.2 shows the same scores as **TABLE 4.1** but for the Tropics and S. Hemisphere.

Tropical height scores show a substantial worsening, particularly at 300 and 250hPa. This is partly a reflection of the change in surface pressure bias which has changed to a negative bias for the trial. This was also true for the first parallel suite run. The detrimental effect is slightly less for this trial, but the impact in the tropics has not been substantially changed by the revised package (see section 3). S. Hemispheric height scores are generally better in the trial for the lower troposphere although the results have larger variation which may be a sampling problem due to the much smaller number of observations. Nevertheless the improvements from T+24 to T+72 are between 2 and 4 %.

Tropical rms errors for temperature are generally smaller for the operational version, although there are some notable improvements at 850hPa and 200hPa for the trial. For the first parallel suite the errors were generally smaller for the trial version (see **TABLE 2.4, Technical Report 128**). This points to the need for further investigation of the tropical response and further developments to the orographic roughness and gravity wave drag schemes. Temperature scores for S. Hemisphere are generally lower for trial . Lower atmospheric rms vector wind errors are better for both regions with changes of 1 to 5%. The tropical errors have been reduced by the increased low level drag from the orographic roughness.Relative humidity scores are mostly better at 850hPa for the trial and worse at 500hPa, with overall evenly scored between operational and trial versions. Rms vector wind errors for 10m winds are better for both regions with the greater impact in the S. Hemisphere. Surface temperature and surface pressure rms errors are also substantially improved there also.

Overall there are reductions in rms errors for most parameters in the S. Hemisphere, although generally not so great as for area 2 and N Hemisphere. In the Tropics there are reductions

%RMS CHANGE (TRIAL-OPERATIONAL) PERIOD 03/12/94-15/12/94											
VERIFICATION AGAINST OBSERVATIONS											
	T+0	T+24	T+48	T+72	T+120		T+0	T+24	T+48	T+72	T+120
AREA	300, Tropics 30N to 30S					AREA	400, S H from 30S				
HEIGHTS						HEIGHTS					
850	-0.1	-6.1	-2.2	1.5	-3.3	850	-0.7	-1.9	-2.4	0.3	2.7
700	0.8	3.4	6.8	8.6	5.0	700	0.7	-1.4	-2.9	-2.4	1.7
500	0.1	4.4	6.2	8.8	12.7	500	-0.4	-3.2	-3.9	-4.5	1.8
300	0.1	5.3	9.3	11.8	18.2	300	0.4	-3.2	-1.5	-2.9	2.7
250	1.6	5.9	10.1	12.4	17.7	250	0.8	-1.8	-0.3	-1.3	3.3
200	1.1	5.0	7.3	10.7	14.5	200	0.2	-1.3	1.0	0.3	3.4
100	0.0	3.7	4.3	6.3	7.0	100	-0.3	1.4	2.6	0.3	1.9
50	0.9	3.3	2.1	2.4	1.3	50	0.5	0.9	1.7	0.5	0.6
Mean	0.6	3.1	5.5	7.8	9.1	Mean	0.1	-1.3	-0.7	-1.2	2.3
TEMPERATURES						TEMPERATURES					
850	-0.3	-3.0	-2.2	0.4	0.8	850	-1.7	-2.1	-1.6	-2.8	-2.0
700	1.2	1.5	2.7	3.1	2.4	700	1.3	-2.0	-5.9	-6.3	4.2
500	0.3	-0.4	3.4	4.7	7.5	500	-1.6	-3.5	-0.4	-2.2	3.0
300	0.6	-0.8	0.3	2.5	6.3	300	-0.5	-6.4	0.2	-0.6	0.3
250	-0.3	0.9	0.2	3.0	4.0	250	-1.6	-2.9	2.4	-1.1	3.0
200	-1.1	-2.1	-2.1	-2.5	0.2	200	-0.7	-2.5	-1.3	0.1	-2.4
100	-1.0	2.7	2.5	2.7	4.3	100	-0.3	-3.3	-2.4	-3.4	1.9
50	-0.3	-2.6	-3.5	-3.4	-2.8	50	0.0	-0.9	-0.5	-0.8	0.5
Mean	-0.1	-0.5	0.2	1.3	2.8	Mean	-0.6	-2.9	-1.2	-2.1	1.1
WINDS						WINDS					
850	1.0	-1.9	-3.3	-2.8	-4.0	850	4.9	-0.9	-2.5	-1.8	-5.3
700	0.3	-0.1	-1.0	-1.3	-1.2	700	-0.9	-2.2	-2.6	-1.4	-4.8
500	-0.7	-0.6	-1.7	-0.5	2.7	500	-0.8	-0.5	-3.5	-1.9	-1.2
400	0.0	0.3	0.5	1.8	5.8	400	-0.1	-0.3	-1.7	0.3	-0.8
300	-0.2	-0.6	-0.8	-0.5	5.6	300	-0.7	-0.9	-0.6	0.6	2.6
250	-0.7	-0.8	-0.1	0.2	4.7	250	-0.6	0.3	-0.5	0.8	3.8
200	-0.6	-0.6	0.0	0.7	2.2	200	-0.7	2.2	-0.2	0.5	2.6
100	0.2	-2.3	-1.1	0.0	5.9	100	-0.1	-0.3	-3.4	-1.3	4.5
Mean	-0.1	-0.8	-0.9	-0.3	2.7	Mean	0.1	-0.3	-1.9	-0.5	0.2
RH						RH					
850	-0.5	-0.9	-2.4	-1.7	-3.2	850	-1.6	-5.0	-1.6	0.2	0.1
700	-1.3	0.3	3.1	0.9	2.7	700	2.0	0.9	0.7	-2.0	2.3
500	-0.6	-0.3	1.1	4.7	4.2	500	4.8	5.1	3.0	2.6	1.5
Mean	-0.8	-0.3	0.6	1.3	1.2	Mean	1.7	0.3	0.7	0.3	1.3
SURF						SURF					
-pmsl	-0.7	-2.2	-0.9	1.0	-0.5	-pmsl	-1.5	-7.6	-6.3	-4.2	-2.8
-temp	-0.5	-0.7	-1.0	-1.3	-1.6	-temp	-2.5	-1.0	-2.8	-4.8	-5.3
-wind	2.1	-0.4	-0.7	-0.7	-0.9	-wind	-0.9	-2.0	-2.1	-2.4	-2.2
Mean	0.3	-1.1	-0.9	-0.3	-1.0	Mean	-1.6	-3.5	-3.7	-3.8	-3.4
Mean all	0.0	0.3	1.2	2.4	3.9	Mean all	-0.1	-1.5	-1.3	-1.4	0.7

TABLE 4.2

in rms errors for some parameters but the poor tropical height errors are noteworthy and the pattern of impacts is rather more mixed, so that the operational version is favoured. The trial is better overall in the S.Hemisphere

TABLE 4.3 summarises the overall performance of the trial based on the scores in **TABLES 4.1, AND 4.2**. It shows the number of scores for which the rms changed by greater than 1% to decide whether the trial or operational were better in each area. For changes less than 1% operational and trial were deemed equal. With 30 fields and 5 verification times there are 150 scores in total for each area. The clear advantage of the trial version for the N. Atlantic and N.Hemisphere extratropics is demonstrated, with positive signals substantially outweighing the negative signals. The operational model performed better for the tropics, where the heights were so much worse and temperatures generally slightly worse for the trial. For the southern hemisphere the signal is not so strong but the trial is again favoured.

TABLE 4.3 : Summary of objective verification scores from **TABLES 4.1, AND 4.2**

Area	Trial better	equal	operational better
N Atlantic ("2")	100	40	10
N Hemisphere	107	33	10
Tropics	29	61	60
S Hemisphere	65	56	26

TABLES 4.4, AND 4.5. summarise the percentage changes in rms errors for verification against analyses. The results are broadly similar to those for verification against observations with large improvements in area 2 and N. Hemisphere in height, temperature and vector wind errors, particularly at T+24,T+72, with again many of the changes of 10% or more. Like the verification against observations, the impact is reduced at T+120. The benefits of increased and reduced drag at lower and upper levels respectively is shown by the reduced vector wind errors at 850 and 100hPa, and reduced errors at other levels (**TABLE 4.4**).

The tropical height rms errors again show as very much worse with degradations of up to ~18% at 500hPa. Heights in the S.Hemisphere are also mostly worse, which contradicts the picture given by verification against observations. Temperatures in the tropics are generally worse for the trial, as found when measured against observations. Winds are improved at 850 hPa in the tropics and S.Hemisphere, but generally the errors are similar or are better for the operational . Relative humidity errors are lower for the trial .The rms surface pressure errors are generally better for the trial in both the tropics and S. Hemisphere.

As for the assessment against sondes and synop reports the verification based on analyses shows a similar picture. There are large or very large improvements in many parameters in the N.Hemisphere and N. Atlantic regions and there are few major discrepancies between the

RMSE	% CHANGE(TRIAL-OPERATIONAL) PERIOD 03/12/94-15/12/94						
	T+24	T+72	T+120		T+24	T+72	T+120
VERIFICATION AGAINST ANALYSES							
AREA	2			N.HEM			
HEIGHT				HEIGHT			
850	-11.0	-11.4	-9.4	850	-14.5	-9.9	-5.7
700	-7.9	-8.7	-7.8	700	-13.2	-9.1	-6.0
500	-4.0	-6.4	-3.9	500	-7.3	-6.8	-4.6
300	-3.4	-4.7	2.5	300	-4.5	-4.5	0.6
250	-3.7	-3.9	4.4	250	-4.5	-3.5	2.1
200	-3.9	-2.9	6.5	200	-5.1	-3.7	2.9
100	-6.9	-6.6	6.7	100	-11.5	-11.7	-1.0
50	-5.9	-8.2	5.8	50	-9.8	-10.2	-1.4
Mean	-5.8	-6.6	0.6	Mean	-8.8	-7.4	-1.6
TEMP				TEMP			
850	-3.8	-3.8	-4.4	850	-4.2	-1.1	-3.1
700	-3.3	-4.2	-2.7	700	-1.6	0.0	-0.7
500	0.0	-2.7	6.9	500	0.0	-0.8	5.1
300	-0.8	-0.4	2.1	300	-2.2	-2.1	-0.6
250	-1.4	-2.2	-0.8	250	-2.8	-4.5	-5.1
200	-2.3	-5.7	-1.0	200	-5.0	-8.2	-6.7
100	-2.6	-6.3	-3.6	100	-7.8	-9.9	-7.7
50	-2.7	-6.8	0.0	50	-7.1	-9.4	-6.6
Mean	-2.1	-4.0	-0.4	Mean	-3.8	-4.5	-3.2
WIND				WIND			
850	-6.1	-4.2	-6.2	850	-9.1	-5.4	-2.9
700	-2.7	-2.4	-4.2	700	-5.4	-3.5	-2.9
500	-0.3	-2.8	-3.5	500	-1.8	-3.2	-2.4
400	-1.2	-3.2	-1.7	400	-1.4	-3.2	-0.7
300	-1.5	-2.4	1.7	300	-0.3	-2.3	2.0
250	-1.0	-2.3	2.4	250	-0.6	-2.0	2.0
200	-1.6	-3.3	2.9	200	-2.8	-2.5	0.7
100	-8.1	-13.3	-2.2	100	-11.8	-11.4	-7.7
Mean	-2.8	-4.2	-1.4	Mean	-4.2	-4.2	-1.5
RELHUM				RELHUM			
950	-4.9	-6.7	-6.7	950	-2.8	-3.0	-3.0
850	-4.1	-6.2	-3.9	850	-2.7	-3.5	-2.5
700	0.3	-2.8	-2.9	700	0.4	-2.9	-1.7
500	0.2	-2.5	-1.8	500	0.0	-2.2	-1.1
Mean	-2.1	-4.6	-3.8	Mean	-1.3	-2.9	-2.1
PMSL	-10.4	-11.6	-9.8	PMSL	-12.4	-8.4	-4.8

TABLE 4.4

RMSE	% CHANGE(TRIAL-OPERATIONAL) PERIOD 03/12/94-15/12/94						
	T+24	T+72	T+120		T+24	T+72	T+120
VERIFICATION AGAINST ANALYSES							
TROPICS				S.HEM			
HEIGHT				HEIGHT			
850	4.5	2.3	7.2	850	-4.0	-0.2	1.3
700	8.5	10.6	15.9	700	-2.1	0.4	2.0
500	12.0	16.5	18.2	500	-0.9	1.3	3.0
300	8.9	14.8	13.8	300	0.0	2.1	2.8
250	9.1	14.6	12.8	250	0.4	2.8	3.6
200	9.7	13.7	11.1	200	1.2	3.5	4.5
100	10.1	9.6	7.8	100	2.6	3.8	4.3
50	4.3	4.9	4.1	50	2.1	1.8	-0.4
Mean	8.4	10.9	11.4	Mean	-0.1	1.9	2.6
TEMP				TEMP			
850	-2.4	-3.5	-3.5	850	-0.7	-1.0	0.5
700	1.2	4.0	3.1	700	-1.4	-1.5	1.7
500	1.7	2.6	3.4	500	0.0	0.0	0.9
300	1.4	3.6	1.6	300	0.8	0.4	1.0
250	1.1	2.5	1.0	250	0.0	0.4	0.9
200	0.0	-0.6	-2.7	200	-0.7	1.9	-1.1
100	2.8	-0.9	-1.3	100	-1.2	0.6	2.4
50	0.0	1.9	0.0	50	-1.3	0.0	3.4
Mean	0.7	1.2	0.2	Mean	-0.6	0.1	1.2
WIND				WIND			
850	-5.7	-6.0	-6.9	850	-2.7	-0.7	-0.6
700	-0.6	-2.7	-2.3	700	-1.1	-0.2	0.2
500	0.6	0.3	2.9	500	0.5	1.0	1.6
400	0.7	-0.2	2.2	400	0.6	1.2	1.7
300	0.0	-0.8	0.4	300	0.4	1.4	2.0
250	0.1	-0.1	0.1	250	0.6	1.9	2.8
200	0.8	1.0	1.6	200	0.6	2.1	3.4
100	0.8	2.1	4.9	100	-0.6	1.3	3.3
Mean	-0.4	-0.8	0.4	Mean	-0.2	1.0	1.8
RELHUM				RELHUM			
950	-1.9	-4.5	-2.9	950	-5.0	-5.8	-5.4
850	-3.9	-5.5	-7.4	850	-2.4	-1.9	-4.1
700	-0.6	-3.1	-2.3	700	-0.3	0.5	-0.6
500	0.5	-1.4	-2.4	500	1.7	0.4	-1.1
Mean	-1.5	-3.6	-3.8	Mean	-1.5	-1.7	-2.8
PMSL	1.7	-2.7	-0.9	PMSL	-5.1	-1.6	0.4

TABLE 4.5

verification methods.

TABLE 4.6 summarises the overall performance of the trial based on the scores in **TABLES 4.4, AND 4.6**. It shows the number of scores for which the rms changed by greater than 1% to decide whether the trial or operational were better in each area,with changes less than 1% deemed equal. With 29 fields and 3 verification times there are 87 scores in total for each area. The clear advantage of the trial version is demonstrated with positive signals outweighing the negative signals for all areas except the tropics where the heights were so much worse and S. Hemisphere where the heights were generally worse.

TABLE 4.6 : Summary of objective verification scores from **TABLES 4.4, AND 4.5**

Area	Trial better	equal	operational better
N Atlantic ("2")	67	10	10
N Hemisphere	69	13	5
Tropics	22	22	43
S Hemisphere	18	37	32

4.2 BIASES AND VERTICAL DISTRIBUTION OF ERRORS

PMSL

FIGURE 4.1 shows the bias and rms errors ,verified against observations, from T+0 to T+120 for mean sea-level pressure for N Atlantic and N Hemisphere. The improved rms has already been noted but the change to the bias is a remarkable improvement. The operational model's negative bias has almost been entirely removed. In the earlier trial the increased low level and surface drag were too strong and resulted in a positive bias (see Fig 2.1,Technical note 128). The operational version is generally too cyclonic which the trial package reduces.

In the tropics, **FIGURE 4.2**, there is a reduction in mean pressure and a positive bias operationally has been replaced by a negative error which is smaller at T+48 but larger by T+120. This is partly responsible for the very much worse rms height errors. In the S Hemisphere there is a beneficial slight reduction in positive bias.

FIGURE 4.3 shows scatter plots of rms errors in pmsl for the trial against operational versions from the 11(T+72) or 9 (T+120) individual cases (05/12/94 - 15/12/94). In area 2 at T+72 the trial is better in 7 cases with 3 equal or nearly equal to the operational version. By T+120 the trial is better in 5 out of 9, with 1 equal. For the N Hemisphere the trial is clearly better for 9 of the 11 cases and by T+120 the trial is again better in 15 out of 9, with 1 equal. This shows that the trial is better more often on a daily basis and that the mean verification scores are not dominated by one or two exceptional cases.

HEIGHT

FIGURE 4.4 shows the bias (left) and rms (right) height error profiles for T+72 for area 2 (top) and N Hemisphere (bottom). **FIGURE 4.5** is the same but T+120. For the N Hemisphere, the operational negative bias has been much reduced so that now there is almost zero bias up to 500hPa. The magnitude of the changes in bias, which are approximately constant with height below 300hPa are consistent with the increase in surface pressure bias (**FIGURE 4.1**). Although the biases are still improved at T+120, the rms errors are worse between 300 and 200hPa, as already noted in **TABLE 4.1**.

FIGURES 4.6 AND 4.7 are the same as **4.4 and 4.5** but for the tropics and S Hemisphere. In the tropical band, the larger negative bias of the trial compared to the operational is again approximately constant for levels below 300hPa and explained by the larger negative bias of the surface pressure. Whilst this is probably responsible for an appreciable part of the increases in rms errors in the tropics, the changes in bias and rms are generally small for the S Hemisphere.There is a shift from improved rms at T+72 to worse at T+120, but the relatively small number of observations (~30 per day) should lead to caution on the reliability of such conclusions.

Similar changes in bias are found from the verification against analyses (not shown).

FIGURE 4.8 shows scatter plots or rms errors of 500hPa height. At T+72 more cases favour the operational version in area 2 , although the trial cases which are better show a larger improvement. In the N Hemisphere the trial is clearly better in 7 out of 11 cases. By T+120, the trial and operational are more evenly matched for both regions.

TEMPERATURE

FIGURE 4.9 shows the bias (left) and rms (right) temperature error profiles for T+48 for area 2 (top) and N Hemisphere (bottom). **FIGURE 4.10** is the same but T+120. The trial has reduced the cold bias below 500hPa but has increased it around 300hPa by ~0.2 degree (T+48), ~1/4 degree (T+120). Rms scores are better at all levels at T+48 but are worse at 500hPa and below at T+120. Verification against analyses shows a similar pattern of changes (**FIGURE 4.11**). However the warming is now confined to 850hPa only and the rms errors at T+120 are slightly at 500hPa. This implies that the lower atmospheric warming is largely restricted to land, since the distribution of sondes is mostly over land. The cooling at upper levels is consistent with reduced gravity wave drag in the lower stratosphere and increased equator to pole temperature gradient to maintain thermal wind balance (see Technical Report 127).

Tropical temperatures are mostly slightly colder by ~0.1-0.2 K at T+120 (**FIGURE 4.12**), with cooling in the southern hemisphere from 500 to 200hPa. Rms scores are generally worse for the trial as noted above in **TABLE 4.2**.

WINDS

The overall effect of the trial package is for reduced wind speeds but generally better rms

vector wind errors. The analysed winds (**FIGURE 4.13**) show increased negative bias from 850hPa which is largest to 300hPa (smallest) in area 2 and N Hemisphere. The underanalysis of wind strength operationally is believed to be due, at least in part, to the assimilation of layer averaged winds. The evidence here seems to suggest that the observations are being fitted even less well in the trial. However the reduction in mean wind speed is less than for the first parallel suite trial (see Fig 2.14, Technical report 128), reflecting the smaller effective roughness lengths.

The T+24 forecast winds (**FIGURE 4.14**) from the trial show greater underforecast strength, but the vector wind errors are mostly comparable to the operational with generally slight improvements. The difference in behaviour of the wind speed and vector wind errors suggests the trial version is forecasting direction more accurately . Operationally the winds are scaled before dissemination. The verification has been performed using unscaled winds for both trial and operational. Given the change in wind bias the scaling factor will need to be reconsidered since the forecast wind strength, as a percentage of observed, now varies more with height in the trial version (**FIGURE 4.15**).

FIGURE 4.16 shows the T+24 scores for the tropics, where the increased surface roughness has resulted in a mean negative bias at 850hPa, whereas at 100,300 and 400hPa the bias has been reduced. In the S hemisphere the speed bias is generally worse for the trial. Mostly the rms errors are better for the trial or the same in both areas.

The reduction in wind strength is greatest over land as expected so that verification against analyses (**FIGURE 4.17**) shows smaller changes generally, especially for the larger N Hemisphere area (cf **FIGURE 4.14**).

The surface wind biases are made ~1/2 knot lighter in the extratropics and are similar in the tropics (**FIGURE 4.18,** left).These changes are smaller than for the first trial and partly reflect an improved derivation of the 10m wind from level 1 winds[1]. The surface winds are generally too strong over land especially during winter so the trial is closer to zero bias for area 2 and Northern hemisphere . Surface wind speeds over the sea are reduced less , when compared to "sea" stations. (NB many of the stations classed as "sea" by the verification scheme are actually land coastal stations or island stations and may not be representative of conditions over the open ocean.) Reduced lowest level winds could affect the global wave model which are driven by them. However the assessment from the first trial was that the very slight reduction in wind speed over the oceans would not cause concern with the wave model (Holt, personal communication).

SURFACE TEMPERATURE

FIGURE 4.19(left) shows the surface temperature biases to be reduced by ~0.4-0.6 degree outside the tropics and by ~0.25 degree over the tropical region. Locally the changes can be

[1] An error was subsequently found which caused the winds to be strongly overestimated over points with large orographic roughness. The verification stations are generally not affected by this.

much larger (see section 5). The rms and biases are better in the trial for all regions.

RELATIVE HUMIDITY

FIGURE 4.20 shows the relative humidity biases and rms scores for area 2 and N Hemisphere. For area 2 the trial is beneficially drier due to the warming in the lower atmosphere. This change has beneficial impact on cloud and precipitation (see sections 6 and 7, where the LAM precipitation verification shows the incidence of spurious light rain has been reduced). The N Hemisphere also has dried at lowest levels but now the overall bias is worse. Rms errors are reduced for both regions at all levels.

4. 3 SUMMARY

The overall objective assessment shows the trial to have several beneficial impacts and particularly up to T+72, in area2 and the N Hemisphere, a large reduction in error scores. The first trial was generally somewhat worse than operational at the short periods and had a larger beneficial impact at T+120. The deficiency in too positive surface pressure bias in the extratropics that was found in the first trial has been corrected. In the tropics the negative error in surface pressure has been slightly improved but the large resultant changes in height errors are still a cause for concern and require further investigation. The general reduction in wind strengths is not so severe as for the first trial and the rms vector wind errors are improved generally.

5. SUBJECTIVE ASSESSMENT - GLOBAL MODEL

This trial ran prior to the operational change on December 13th, hence the subjective assessment was complicated by the inclusion of the superadiabatic lapse rate correction changes in the trial forecasts only. The impact was dominated by the new gravity wave drag and orographic roughness changes but the superadiabatic correction changes had a noticeable impact upon convective precipitation and low cloud.

T+24

In this second parallel suite trial, the impact of the new gravity wave drag and revised orographic roughness at T+24 was much less than in the first trial, with no over-filling of depressions overland. However, the impact, although reduced, was still noticeable as the difference charts in **FIGURE 5.1** indicate. These charts show the mean sea level pressure differences, (trial - operational), at T+24 meaned over thirteen days of the parallel suite trial. In the Northern Hemisphere, **FIGURE 5.1a**, there was a general small rise in pressure at T+24 north of 45N, especially over land, with the maximum impact (+3hPa) over Sakhalin, in southeast Russia. In the Southern Hemisphere, **FIGURE 5.1b**, the biggest differences were over Antartica, but there was a small rise of pressure of 1-2hPa over the Falkland Islands and Tierra del Fuego. Generally, trial depressions were less deep by 1-3hPa. In the assessment of the few depressions which differed by 4hPa or more, the trial depressions were mostly closer to the verifying analysis, even over Canada.

FIGURE 5.2 shows the largest difference seen between trial and operational depressions over Canada at T+24. The operational T+24 forecast for 12Z 9th December, **FIGURE 5.2b**, predicted the depth of the depression near Calgary to be 1006hPa, which was 6hPa deeper than the trial depression, 1012hPa, shown in **FIGURE 5.2b**. The verification, **FIGURE 5.2c**, analysed a depression of 1010hPa over Calgary, which was closer to the trial value.

Overall there was a decrease in low cloud amount at T+24, partly due to the orographic roughness (slight decrease to lee of high ground) and partly due to the superadiabatic lapse rate correction changes. The biggest decrease in low cloud was due to a reduction in ice cloud, especially noticeable near the North Pole. There was an increase in dynamic rainfall over high ground, especially noticeable over the Rockies and Andes, due to the orographic roughness and increased coastal convergence. Convective rainfall was increased slightly over the North Atlantic and in the Tropics due to the impact of the superadiabatic lapse rate correction changes.

The orographic roughness resulted in a slight decrease in low level wind speeds. **FIGURE 5.3a** shows the mean difference at T+24 over the U.K.. The differences indicate a very small reduction in wind speed of 0.5-1.0ms^{-1}, increasing to 2.0ms^{-1} over the Scottish mountains. Bullseyes seen in the 10m wind difference charts near high ground indicated a problem with the 10m wind diagnostics but tests showed that the level 1 winds were correct.

There were small differences between trial and operational 250hpa jet maxima at T+24, but the majority were within 3ms^{-1}. Assessment of the few larger differences favoured the trial forecasts. The cross-section in **FIGURE 5.3b** shows the differences between the trial and operational westerly wind components at T+24, meaned over the period 12Z 03/12/94 to 12Z 16/12/94. The main impact of the trial changes was a small reduction in the westerly component in the Northern Hemisphere, 30-50N, with the maximum impact 0.75ms^{-1} at 700hPa. The increase in the westerly component at 40N, 100hPa was due to the reduction in the gravity wave drag applied in the stratosphere in the trial. The low level differences in the Tropics at 0-20N indicated a reduction in the easterly winds.

Overall the impact of the new gravity wave drag and revised orographic roughness at T+24 was small but beneficial, with none of the excesses of the previous trial.

T+72 / T+120

Overall in this second trial, the operational and trial forecasts followed the same evolution pattern although there were some significant differences in detail. The impact of the new gravity wave drag and orographic roughness could be seen clearly, with most trial depressions and cold pools being less deep and generally higher values of mean sea level pressure and 500hPa contours. A few evolution changes, especially at T+120, resulted in the opposite effect and in particular, a few depressions over Newfoundland developing south of 50N, were slightly deeper in the trial forecasts.

In the North Atlantic, assessment of mean sea level pressure and 500hPa strongly favoured the trial, with most trial depressions and cold pools being closer to the analysis . In the North Pacific and in the Southern Hemisphere generally, assessment was evenly balanced between the trial and operational forecasts. The differences between the operational and trial T+72 mean sea level pressure forecasts in the Northern Hemisphere, meaned over the period 12Z 5/12/94 to 12Z 18/5/94, can be seen by comparing **FIGURES 5.4 (a) and (b)** respectively. The differences are indicated in **FIGURE 5.4c**. The main impact of the trial changes was to raise the pressure north of 50N, with the maximum impact (4hPa) over Northern Canada and Sakhalin, in Southeast Russia.

The verification of the T+72 operational forecasts for the Northern Hemisphere against the operational analysis (forecasts - analysis), **FIGURE 5.5a**, shows that the forecasts had large negative errors north of 55N. The largest errors were over Northern Canada associated with the northeastern edge of the Pacific storm track, over the Greenland and Norwegian Seas to the north of the Atlantic storm track, and over Russia in the Siberian high pressure area. Pressure was also too high over the central Atlantic, 45-50N.

The comparable verification for the T+72 trial forecasts in the Northern Hemisphere against the operational analysis, **FIGURE 5.5b**, indicates the improved performance of the global model. Although there were still negative errors around the North Pole, they were smaller than in the operational forecasts. The only drawbacks were the slightly increased positive errors over the Great Lakes and Hudson Bay in Canada and also over Japan and the Northwest Pacific.

Over the Southern Hemisphere, the differences between operational and trial forecasts at T+72 were much smaller than in the Northern Hemisphere. However, the difference chart, **FIGURE 5.6c**, indicates that mean sea level pressure tended to be slightly higher in the trial forecasts over the Falkland Islands and Cape Horn, associated with the northern edge of the storm track. A comparison of the mean errors for the operational and trial T+72 forecasts in **FIGURES 5.7a/b** respectively, shows that the trial forecasts were a slight improvement over the South Atlantic.

The zonal mean wind cross-sections in **FIGURE 5.8a/b** compare the trial and operational T+72 forecasts of the westerly components, meaned over the period 12Z 05/12/94 to 12Z 18/12/94, using 13 standard levels between 950hPa and 10hPa. The difference chart, **FIGURE 5.8c**, shows the differences between the trial and operational 'u' wind components. The main impact is seen in the Northern Hemisphere at 40N and is very similar to the impact at T+24 described earlier.

The changes in the meridional wind circulation seen in **FIGURE 5.9c** are similar to those discussed in section 3.1. There is an increased thermally 'indirect' circulation at 30-50N and also an increase in the Hadley circulation at 20N -10S, which is less evident in the diagnostics discussed in section 3.1. This general increase in the mean meridional circulation on introducing the new parametrisations makes the model systematic error in the meridional wind worse.

The following examples illustrate some of the differences seen at T+72/120. The analysis for 12Z 12/12/94, **FIGURE 5.10c**, shows a deep depression, depth 975hPa, centred just to the north of Newfoundland. The trial and operational T+72 forecasts verifying at this time, **FIGURES 5.10a/b** respectively, were very good, both predicting a deep depression over Newfoundland. The trial depression, depth 978hPa, was 9hPa less deep than the operational depression but verified better against the analysis.

T+120 forecasts were more difficult to assess since the evolution and detail errors were larger. The next example illustrates the differences in detail seen over the North Atlantic at T+120. **FIGURES 5.11 a/b** compare the trial and operational T+120 forecasts verifying at 12Z 10/12/94. Although the large scale features were similar, there were large differences in detail associated with the depression east of Iceland, the central Atlantic and the depression east of Hudson Bay. The Icelandic depression had a single centre in the trial forecast, but the operational forecast had a complex low with a second deep centre just north of Scotland. The depression was too deep in both forecasts but the analysed centre, **FIGURE 5.11c**, was closer to the trial forecast. In the central Atlantic at 40N 40W, the analysis featured a depression, depth 977hPa, which was not predicted by either forecast. However, a comparison of the the trial and operational forecasts shows that the trial was closer to developing a low in this position. The depression predicted to the east of Hudson Bay by both versions was 12hPa deeper in the operational forecast. but both forecasts were incorrect. The trial forecast was correct at predicting the depression further north at 60N 80W but the operational forecast was better at predicting the trough near Newfoundland.

The final example shows the typical differences seen between trial and operational forecasts at T+120 in the Southern Hemisphere. Comparing the trial and operational T+120 forecasts verifying at 12Z 12/12/94 in **FIGURES 5.12 a/b** respectively, the mean sea level pressure was slightly higher in the trial, and this compared better with the verifying analysis in **FIGURE 5.12c**.

5.1 CONCLUSIONS FROM THE SUBJECTIVE ASSESSMENT- GLOBAL MODEL

1. Most trial depressions and cold pools were less deep and verified better against the analysis.

2. Slight increase in precipitation.
   (a) Slight increase in dynamic precipitation over coasts and high ground.
   (b) Slight increase in convective precipitation over North Atlantic Ocean and also in theTropics due to the superadiabatic correction changes

3. Reduction of low cloud .
   (a) Slight decrease to lee of high ground (due to orographic roughness)
   (b) Less ice cloud (due to the superadiabatic correction changes)

4. Slight reduction in 10m wind speed over land.

5. Slight reduction in westerly bias.

6. Slightly warmer boundary level at 12z overland.

6. OBJECTIVE VERIFICATION - LIMITED AREA MODEL

The analyses and forecasts were verified against observations (Sondes and synops) for the period 02/12/94 to 15/12/94 as for the global model. Verification was also performed against analyses, each suite was verified against its own analyses for the same period. Time-mean results will mostly be discussed here . Results for forecast times T+0, T+24 and for areas "5", "88" and for analyses "888" will be given. Area "5" is the near UK from Iceland to mid Spain, area "88" is 80W-40E, 30-80N and "888" is the full LAM area.

6. 1 RMS ERRORS -OVERALL SUMMARY

Only a brief summary of the main results will be given since most of the major impacts have already been described for the global model in section 2.

TABLE 6.1 summarises the objective scores for verification against observations. It shows the percentage changes in rms errors for heights, temperatures and winds (6 levels each) and relative humidity (3 levels) and 3 surface fields. A negative value shows the trial to be an improvement. Column and surface-means are also shown.

The largest reductions in height, temperature and wind rms errors are at 850hPa. T+24 forecast winds are greatly reduced also. Height and temperature errors are generally much better for the trial. All the surface errors are reduced by appreciable amounts except the surface temperatures which for the smaller area "5" are significantly worse.

TABLE 6.2 summarises the overall performance of the trial based on the scores in **TABLE 6.1**. It shows the number of scores for which the rms changed by greater than 1% to decide whether the trial or operational were better in each area. For changes less than 1% operational and trial were deemed equal. With 24 fields and 2 verification times there are 48 possible scores in total for each area.

As with the global model this simple count shows the benefits of the trial outweighing the disadvantages.

%RMS CHANGE (TRIAL-OPERATIONAL) PERIOD 03/12/94-15/12/94					
VERIFICATION AGAINST OBSERVATIONS					
	T+0	T+24		T+0	T+24
AREA	5		AREA	88	
HEIGHTS			HEIGHTS		
850	-2	-15.5	850	-1	-12.1
500	1.9	-10.2	500	0	-6
300	-0.5	-6.1	300	0	-4.4
250	0.3	-2.8	250	0.1	-3.4
200	2.9	0.8	200	0	-1.7
100	1.8	1.6	100	-1.3	-3.1
mean	0.7	-5.4	mean	-0.4	-5.1
TEMPERATURES			TEMPERATURES		
850	-5.6	-6.1	850	-3.7	-3.4
500	-0.7	-5.5	500	0	-2.3
300	-1.2	-1.7	300	-0.8	-1.9
250	-0.1	-5.2	250	-1.4	-3.3
200	0.1	-3.7	200	0.6	-4.4
100	0.7	-1.7	100	0.7	-0.7
mean	-1.1	-4	mean	-0.8	-2.7
WINDS			WINDS		
850	-0.1	-9	850	-4	-6.5
500	-0.6	-2.4	500	-0.7	-1.5
300	0.4	-6.1	300	-0.7	-4.6
250	0.1	-3.6	250	-0.4	-2
200	-0.3	-2	200	-0.8	-3.2
100	-1.4	-7.8	100	-0.1	-7.2
mean	-0.3	-5.1	mean	-1.1	-4.2
RH			RH		
850	0.1	-2.3	850	0.4	-3.8
700	-1.8	-3.5	700	-2.8	-2.8
500	-1.6	-0.1	500	-2.7	-1.7
mean	-1.1	-2	mean	-1.7	-2.8
SURF			SURF		
-pmsl	-0.7	-12.1	-pmsl	0.6	-10
-temp	3.5	2.1	-temp	1.1	0.6
-wind	-0.9	-4.1	-wind	-2.7	-4.8
mean	0.6	-4.7	mean	-0.3	-4.7
mean all	-0.2	-4.5	mean all	-0.8	-3.9

TABLE 6.1

TABLE 6.2 : Summary of objective verification scores from TABLE 6.1

Area	Trial better	equal	operational better
5	26	16	6
88	29	18	1

TABLE 6.3 summarises the objective scores for verification against analyses. The largest beneficial impacts of the trial are again seen at 850hPa for heights and winds and at 100hPa for winds. Surface pressure errors are also reduced. Generally the scores are better than the operational. The overall summary is shown in TABLE 6.4. With 23 fields and 1 verification times there are 23 possible scores in total for each area. These results show the trial to be overwhelmingly better than operational, and is not surprising given the short period results for the global model.

TABLE 6.4 : Summary of objective verification scores from TABLE 6.3

Area	Trial better	equal	operational better
5	18	3	2
88	18	5	0
888	23	0	0

6.2 BIASES

FIGURE 6.1 (left) shows the reduction in negative bias of surface pressure for areas 5 and 88 similar to that found with the global model for the north Atlantic (area 2).

FIGURE 6.2 shows the warmer surface temperatures and beneficial reduction in bias. However the T+24 rms errors are noticeably worse.

FIGURE 6.3 (left) shows the positive surface wind bias for the operational is much reduced for the trial, without producing as bad a negative bias as was found for the first parallel suite run.

6. 3 LAM PRECIPITATION VERIFICATION

The operational and trial precipitation accumulations per 6 hour periods from T+0 to T+24 were verified against station observations. The results are presented in contingency tables for the following categories of accumulated precipitation - 0, <0.1mm, L, 0.1 < P <2mm, M

RMSE % CHANGE (TRIAL-OPERATIONAL) PERIOD 03/12/94-15/12/94					
VERIFICATION AGAINST ANALYSES					
	T+24		T+24		T+24
AREA	5	AREA	88	AREA	888
HEIGHT		HEIGHT		HEIGHT	
850	-11.6	850	-10.3	850	-10.6
500	-5.2	500	-3.8	500	-5.5
300	-3.5	300	-2.4	300	-4.7
250	-3.2	250	-1.2	250	-3.9
200	-2.1	200	-0.4	200	-3.3
100	-3.5	100	-2.6	100	-9.5
TEMP		TEMP		TEMP	
850	-2.6	850	-2.4	850	-3.8
500	-0.7	500	0.0	500	-2.5
300	0.7	300	-0.7	300	-2.2
250	1.3	250	-0.7	250	-4.6
200	-2.0	200	-4.1	200	-7.5
100	-1.1	100	-4.4	100	-8.6
WIND		WIND		WIND	
850	-7.4	850	-5.6	850	-6.0
500	-1.5	500	-1.8	500	-2.7
300	-1.7	300	-2.3	300	-2.6
250	-2.6	250	-2.2	250	-2.1
200	-0.8	200	-2.6	200	-3.6
100	-6.6	100	-7.8	100	-14.9
REL	HUM	REL	HUM	REL	HUM
950	-8.6	950	-9.8	950	-9.0
850	-6.8	850	-8.7	850	-7.7
700	-3.8	700	-3.4	700	-3.7
500	1.5	500	-0.7	500	-1.8
PMSL	-10.8	PMSL	-9.1	PMSL	-9.5

TABLE 6.3

TABLE 6.5

OPERATIONAL

WHOLE FINE MESH LAND AREA FORECAST PERIOD= 12- 18					
	OBS				
F/C	0	L	M	H	
0	57.2	3.1	0.6	0.1	60.9
L	18.3	9.1	3.1	0.4	31.0
M	1.3	2.5	3.5	0.4	7.7
H	0.1	0.0	0.2	0.1	0.4
	76.8	14.7	7.4	1.1	100.0

BIAS= 1.7
THREAT SCORE(0.1)=45.3
HANS & KUIPER SCORE =0.58
% CORRECT ON YES/NO BASIS=76.6
% CORRECT IN ALL CATEGORIES=69.9
HIT RATE =.838

TRIAL

WHOLE FINE MESH LAND AREA FORECAST PERIOD= 12- 18					
	OBS				
F/C	0	L	M	H	
0	59.5	3.1	0.7	0.1	63.4
L	15.8	9.0	2.9	0.4	28.2
M	1.5	2.5	3.6	0.5	8.0
H	0.1	0.0	0.2	0.1	0.4
	76.8	14.7	7.4	1.1	100.0

BIAS= 1.6
THREAT SCORE(0.1)=47.4
HANS & KUIPER SCORE =0.60
% CORRECT ON YES/NO BASIS=78.7
% CORRECT IN ALL CATEGORIES=72.2
HIT RATE =.830

OPERATIONAL

WHOLE UK AREA FORECAST PERIOD= 12- 18					
	OBS				
F/C	0	L	M	H	
0	29.3	5.4	0.6	0.0	35.2
L	26.2	16.7	6.5	0.0	49.4
M	1.1	5.0	8.0	0.6	14.8
H	0.0	0.2	0.0	0.4	0.6
	56.7	27.2	15.1	1.0	100.0

BIAS= 1.5
THREAT SCORE(0.1)=52.8
HANS & KUIPER SCORE =0.38
% CORRECT ON YES/NO BASIS=66.7
% CORRECT IN ALL CATEGORIES=54.4
HIT RATE =.863

TRIAL

WHOLE UK AREA FORECAST PERIOD= 12- 18					
	OBS				
F/C	0	L	M	H	
0	32.0	5.9	0.4	0.0	38.3
L	22.8	15.9	6.1	0.0	44.8
M	1.9	5.2	8.4	0.4	15.9
H	0.0	0.2	0.2	0.6	1.0
	56.7	27.2	15.1	1.0	100.0

BIAS= 1.4
THREAT SCORE(0.1)=54.4
HANS & KUIPER SCORE =0.42
% CORRECT ON YES/NO BASIS=69.0
% CORRECT IN ALL CATEGORIES=56.9
HIT RATE =.854

2.0< P <10mm and H, P > 10mm. (0=none, L=light, M=medium, H=heavy). The most noticeable impact on the scores was a reduction of the forecasting of light rain when none was observed. The results were consistent for all forecast periods and we will only present T+12-T+18 results here (**TABLE 6.5**) for the UK and whole LAM areas (land).

The bias (forecast rain events/ observed rain events) is lower for the trial and the % correct on a yes/no basis is improved by 2%. The hit rate is correspondingly reduced since there are now fewer spurious rain forecasts (NB a model which forecast precipitation at all points would score 1 for the hit rate since it only measures successful forecasts of precipitation!). The threat scores and Hanssen and Kuipper scores which take account of the false alarm rate show the trial to be better . The contingency tables show a reduction in the light forecast/ none observed category with a smaller increase in the none forecast/ light observed and more correctly predicted none observed/none forecast category. These are largely responsible for the overall improvement of the threat and Hanssen and Kuipper scores.

6. 4 SUMMARY

The overall objective assessment of the LAM shows similar benefits and impacts to that found for the global model in the N Atlantic area. In contrast to the previous parallel suite trial the results now clearly favour the trial and reflect the improved short period results found with the global model. The improvement in surface and lower atmospheric temperatures appears to have had a beneficial effect on removing spurious light precipitation.

7. SUBJECTIVE ASSESSMENT - LIMITED AREA MODEL

a) Mean sea level pressure and 500hPa.

In **FIGURES 7.1 a/b** we compare the trial T+36 forecasts of mean sea level pressure and 500hPa with the corresponding operational forecasts, Figures 7.1 c/d. These forecasts have been meaned over the period 12Z 4/12/94 to 12Z 17/12/94. These charts confirm the subjective opinion that the trial and operational forecasts were very similar with no evolution differences,

However, the new gravity wave drag and revised orographic roughness did have a small but noticeable impact on both mean sea level pressure and 500hPa and this impact is indicated by the difference charts in **FIGURES 7.2 a/b**. The mean sea level pressure difference chart, **FIGURE 7.2a**, gives the differences (trial-operational) between **FIGURES 7.1 (a) and (b)**. The positive differences north of 50N indicate a small rise in pressure in the trial forecasts. The differences over Greenland are due to extrapolation so the largest significant difference (+2/+3hPa) occurred over Canada, in the area of high pressure between the Great Lakes and Hudson Bay. The small positive differences south of Iceland are associated with the North Atlantic storm track. Similarly, the main difference at 500hPa, **FIGURE 7.2b**, was a small rise in contour heights of 2-3dm over Canada west of the Great Lakes. The other noticeable difference was the negative difference over and to the south of Newfoundland.

Comparing the individual forecasts, trial and operational depressions were mainly within +/-3hPa, with the trial depressions tending to be slightly less deep. The two largest

differences between operational and trial depressions was seen in the T+36 forecasts verifying at 12Z 9/12/94. These forecasts are compared in **FIGURES 7.3a/b** respectively. The two depressions concerned are;

(i) 69N 01E operational 967hPa trial 972hpa analysis 967hpa
(ii) 49N 108W operationa 1003hPa trial 1012hpa analysis 1010hpa

Generally the differences were less than this and there was no sign of the trial forecasts filling depressions too quickly. Similarly, most 500hpa lows were slightly less deep in the trial forecasts.

b) Low level winds.

The trial low level winds were slightly lighter over land due to the increased drag at low levels . However, the difference between trial and operational 10m winds was much less than in the first trial. The 10m winds over the U.K., Ireland and Northern France from the trial and operational T+36 forecasts are compared in **FIGURES 7.4 a/b** respectively. These winds have been meaned over the period 12Z 4/12/94 to 12Z 17/12/94. An inspection of these charts indicates that the trial 10m winds were slightly weaker. The differences, highlighted in **FIGURE 7.4c**, show that the main differences were over and to the east of high ground, with the maximum difference ($3ms^{-1}$) over Western Scotland.

During the trial there were a few windy days during which we were able to compare the trial and operational 10m wind forecasts and two examples are described here. One of the windiest times was at 06Z 8th December and the observations in **FIGURE 7.5** show the observed windspeeds at 06Z. Strong or gale force southerly winds over England veered to westerly behind the cold front over Wales. Most observations over England reported mean speeds of 25 knots with 30 knots in exposed areas. The forecast 10m winds at T+30, verifying at 06Z from the oper and trial forecasts are compared in **FIGURES 7.6 a/b** respectively. The forecast winds are very similar but the trial winds are occasionally 5 knots lighter inland.

The 10th December was another windy day and the observed windspeeds at 18Z over the U.K. are shown in **FIGURE 7.7**. Most observations over the Midlands and Northern England reported windspeeds of 20 knots with 15 knots in more sheltered areas. The operational and trial 10m wind forecasts for T+18, verifying at 18Z, are compared in **FIGURES 7.8 a/b** respectively. Again, both sets of winds are very similar, with the trial winds occasionally 5 knots lighter to the lee of high ground, e.g. West Midlands, Central Scotland.

These two cases illustrate the differences between the trial and operational 10m winds. Generally the differences are very small, with the trial winds occasionally 5 knots lighter. Winds inland in areas sheltered by high ground were better predicted by the trial forecasts. However, gales over exposed areas were slightly better in the operational forecast.

c) Temperatures and low cloud.

The T+36 1.5m temperature differences, averaged over the period 12Z 4/12/94 to 12Z

17/12/94, are shown in **FIGURE 7.9a**, with the shaded region indicating a very slight warming in the trial forecasts at 12Z. Over the U.K., the average rise in temperature was 0.2-0.4C and this could be related to a reduction in low cloud. There was a slight cooling (-1C) over the Norwegian mountains and a larger cooling of -4C to -8C around the Greenland coast.

All individual trial forecasts showed a decrease of about 15% in the average low cloud fraction (from 0.30 to 0.25). This reduction was partly due to the orographic roughness (slight decrease to lee of high ground) and partly due to the superadiabatic lapse rate correction changes. The biggest decrease in low cloud was due to a reduction in ice cloud. The mean difference between trial and operational low cloud at T+36, over the period of the trial, is shown in **FIGURE 7.9b**, with the shaded region indicating a reduction of low cloud in the trial forecasts. Over the U.K., the reduction was in the sheltered east.

There was also a slight decrease (approx. 9%) in medium cloud which was present in 10 out of 12 cases examined. The decrease was more noticeable in unstable airmasses over the sea rather than in frontal cloud. An example of a noticeable decrease in medium cloud over the sea can be seen by comparing the T+12 operational and trial forecasts verifying at 12Z 5/12/94 in **FIGURES 7.10 b/c** respectively. The visual meteosat satellite image for 12Z 5/12/94, **FIGURE 7.10a**, shows mainly convective cloud to the west of Ireland over the sea, so the extensive medium cloud predicted by the operational forecast, **FIGURE 7.10b**, was grossly overdone.

d) Precipitation

Each individual forecast showed an overall slight increase in precipitation. In **FIGURE 7.11a,** the shaded area represents the mean increase in convective precipitation in the trial forecasts at T+36. These forecasts have been meaned over the period 12Z 4/12/94 to 12Z 17/12/94. The main increase over the Atlantic Ocean can be attributed to the superadiabatic lapse rate correction in the trial forecasts. This increase was partly due to a slight intensification but also due to a switch from dynamic to convective precipitation. An example of this can be seen by comparing the operational and trial forecasts for T+24, verifying at 00Z 7/12/94,in **FIGURES 7.12 b/c** respectively. The airmass over the Atlantic circulating around the depression was unstable and cold, as indicated by the position of the snow probability lines in **FIGURE 7.12b**. Associated with the snow probability lines at 50-55N, 18-30W, the operational forecast predicted an area of dynamic rain. In contrast, the trial forecast predicted an area of heavy showers. The meteosat infra-red satellite image, **FIGURE 7.12a**, indicated mainly convective cells in this region.

In **FIGURE 7.11b**, the shaded area represents the mean increase in dynamic precipitation in the trial forecasts at T+36. Again, the forecasts have been meaned over the period 12Z 4/12/94 to 12Z 17/12/94. The main impact is a slight increase in dynamic precipitation over coasts and high ground. Over the high ground in Northwest Scotland the increase amounted to 25mm on average for the 36-hour accumulation. There was also a slight decrease in dynamic precipitation over Eastern Scotland to the lee of the Scottish mountains. Over Southeast England, a few cases showed a decrease in very light rain in southwesterly airstreams. The operational forecast for T+12, verifying at 12Z 11/12/94, **FIGURE 7.13b**,

predicted fairly widespread light rain over Southern England. This rain was spurious, as the radar image for 12Z 11/12/94, **FIGURE 7.13a**, confirms. The trial forecast , **FIGURE 7.13c**, was an improvement for Southern England by predicting no rain.

e) 250hPa jets.

A comparison of the mean 250hpa jets at T+24 in **FIGURES 7.14 a/b** , shows that there was little difference between the operational and trial jets. Individual forecasts differed slightly but the assessment was evenly balanced between operational and trial forecasts.

7.1 CONCLUSIONS FROM THE SUBJECTIVE ASSESSMENT- LAM

1. Trial and operational depressions were mostly within 3hPa with the trial depressions tending to be less deep.

2. Overall slight increase in precipitation.
   (a)Slight increase in dynamic precipitation over coasts and high ground.
   (b)Slight increase in convective precipitation in cold unstable airmasses over Atlantic Ocean.

3. Reduction in the amount of spurious light rain predicted over land.

4. Reduction of low and medium cloud .
   (a) Slight decrease of low cloud to lee of high ground (due to orographic roughness)
   (b) Less ice cloud (due to the superadiabatic correction changes)

5 Slight reduction in 10m wind speed over land.

8 CONCLUSIONS

The revisions to the new gravity wave drag and parametrisation of surface roughness due to sub grid scale orography have improved on some of the deficiencies noted in the earlier tests without overmuch degrading the benefits. The second parallel suite trial now shows the package to be performing significantly better than the operational version for many parameters. The package should be implemented as soon as possible to benefit from the improvements this winter. The degradation of the tropical performance needs further investigation, possibly entailing other revisions to the model physics.

There are still several areas where the schemes can be improved which we reiterate:

1) The specification of the surface parameters for the orographic roughness have been

parametrised from the standard deviation of the orography. They should ideally be determined from very high resolution data. Such data is available for most of Europe and North America and a re-specification should be attempted using all available high resolution data with other areas parametrised from the standard deviation. When available the model should be run with the better specification of surface roughness.

2) The surface orographic roughness fields should take account of anisotropy to be consistent with the surface gravity wave stress parametrisation.

3) Little is known about the drag due to very high roughness in steep mountainous areas and the scheme could require further tuning.

4) The gravity wave drag scheme has a number of assumptions concerning the calculation of "surface stress" such as the appropriate wind level and the vertical distribution of drag. These also could be subject to further revisions.

5) In stable boundary layers there is some interaction between the orographic drag and gravity wave parametrisations which may require further modification.

After operational implementation the behaviour of the global and limited area models should be closely monitored and further revisions made as appropriate. The forecast resolution climate run of the Unified Model should provide useful guidance in such revision as will further diagnostic study of the momentum budget.

8 ACKNOWLEDGEMENTS

The new gravity wave drag scheme was first proposed by Glen Shutts (APR division) and has been coded and developed for the Unified Model by David Gregory and James Mitchell (Climate Research division). The orographic roughness scheme has been developed (and modified as outline in section 2) for the Unified Model by Simon Jackson and Roderick Smith. Ancillary field parameters were rederived by Clive Jones and Ruth Evans (all FR division). The corrections to eliminate the superadiabatic profiles were developed by Roderick Smith.

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Figure Captions

Figure 3.1 Zonally averaged pressure-latitude cross sections averaged over 5 case studies from December 1993 at T+120 showing (a) zonal wind mean error (model - analyses) for the operational (OP) model forecasts (b) zonal wind mean error (model - analyses) for the ROGW2 forecasts (c) zonal wind mean difference ROGW2 - OP and (d) as (c) but for ROGW2 - ROGW1.

Figure 3.2 Zonally averaged pressure-latitude cross sections averaged over 5 case studies from December 1993 at T+120 showing (a) Meridional wind from operational analyses, (b) meridional wind mean error (model - analyses) for the OP forecasts (c) meridional wind mean difference ROGW2 - OP and (d) as (c) but for ROGW2 - ROGW1.

Figure 3.3 Zonally averaged pressure-latitude cross sections averaged over 5 case studies from December 1993 at T+120 showing (a) temperature mean error from the OP forecasts (b) temperature mean difference ROGW1 - OP and (d) as (c) but for ROGW2 - ROGW1.

Figure 3.4 Zonally averaged profile of MSLP for the OP, ROGW1 and ROGW2 forecasts and verifying analysis at T+120. Results averaged over the 5 cases from December 1993.

Figure 3.5 Northern Hemisphere MSLP difference fields at T+120 for (a) ROGW2 - OP, and (b) ROGW2 - ROGW1.Results averaged over the 5 cases from December 1993. Panels (c) and (d) as (a) and (b) respectively but for the Southern Hemisphere.

Figure 3.6 Northern Hemisphere MSLP fields showing (a) Analyses corresponding to forecasts at T+120, (b) mean error in MSLP (forecast - analysis) for the OP forecasts at T+120, (c) as (b) but for ROGW1 forecasts, and (d) as (b) but for ROGW2 forecasts. Results averaged over the 5 cases from December 1993.

Figure 3.7 As figure 3.6 but for the Southern Hemisphere.

Figure 3.8 Zonally averaged, daily averaged (T+00 to T+24) zonal wind tendencies due to the Unified Model boundary layer turbulent mixing scheme for (a) ROGW1, (b) ROGW2, (c) ROGW2 - ROGW1. Units are m/s/day.

Figure 3.9 Zonally averaged, daily averaged (T+00 to T+24) zonal wind tendencies due to the Unified Model gravity wave drag scheme for (a) ROGW1, (b) ROGW2,

(c) ROGW2 - ROGW1. Units are m/s/day.

Figure 3.10 RMS vector wind error for Observations-Model for T+72 forecasts from 07/01/94 to 13/01/9 over (a) Northern Hemisphere Extratropics (90N-30N), (b) Tropics (30N-30S) and (c) Southern Hemisphere Extratropics (30S-90S). Observations are Radiosondes and aireps and verification scores are shown for each model level.

Figure 3.11 Temperature bias for Observations-Model for T+72 forecasts from 07/01/94 to 13/01/94 over (a) Northern Hemisphere Extratropics (90N-30N), (b) Tropics (30N-30S) and (c) Southern Hemisphere Extratropics (30S-90S). Observations are Radiosondes and verification scores are shown for each model level.

Figure 3.12 As figure 3.10 but for forecasts from 11/08/93 to 17/08/93.

Figure 3.13 As figure 3.11 but for forecasts from 11/08/93 to 17/08/93.

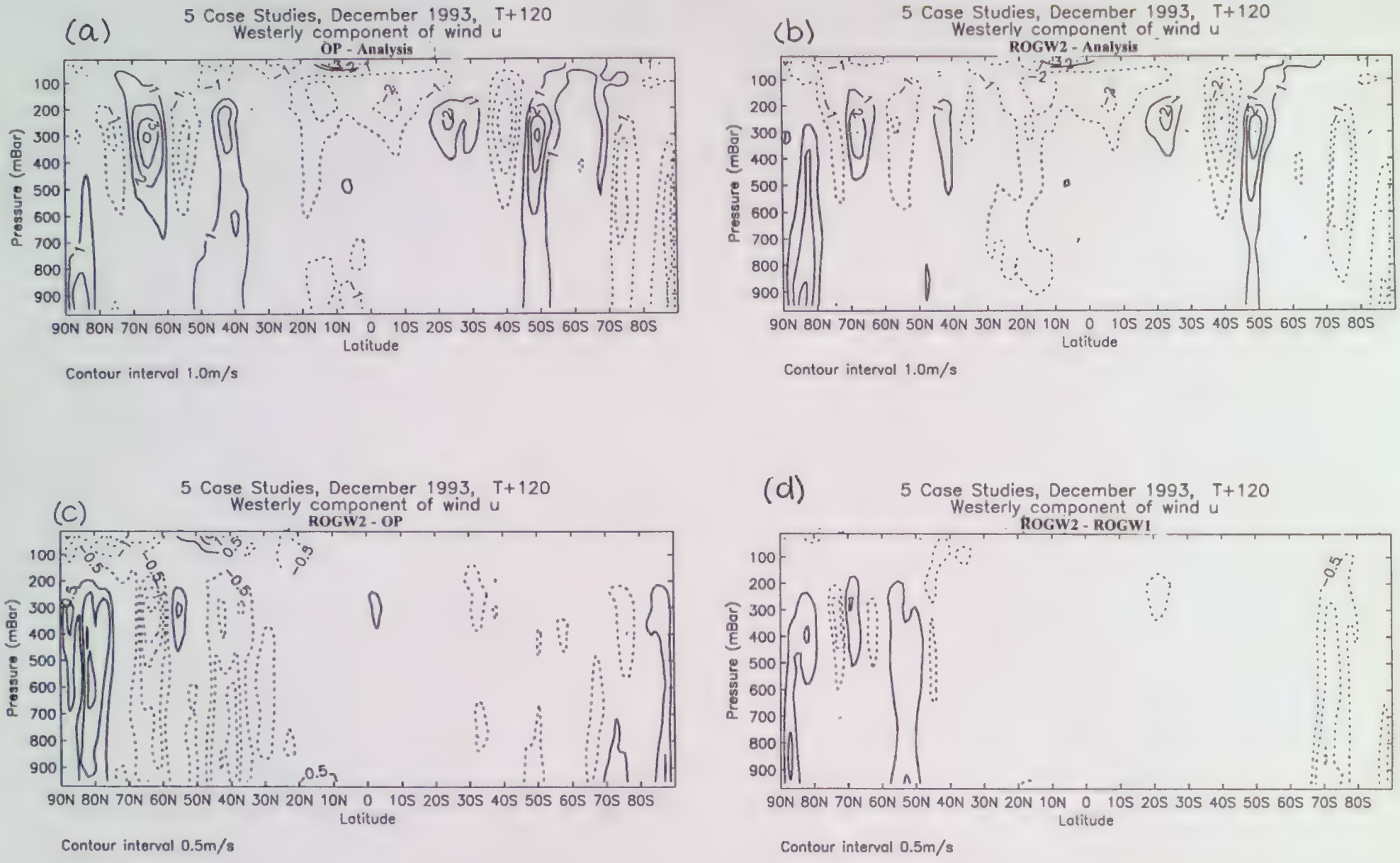

(a)
5 Case Studies, December 1993, T+120
Westerly component of wind u
OP - Analysis
Pressure (mBar)
100
200
300
400
500
600
700
800
900
90N 80N 70N 60N 50N 40N 30N 20N 10N 0 10S 20S 30S 40S 50S 60S 70S 80S
Latitude
Contour interval 1.0m/s
(b)
5 Case Studies, December 1993, T+120
Westerly component of wind u
ROGW2 - Analysis
Pressure (mBar)
100
200
300
400
500
600
700
800
900
90N 80N 70N 60N 50N 40N 30N 20N 10N 0 10S 20S 30S 40S 50S 60S 70S 80S
Latitude
Contour interval 1.0m/s
(c)
5 Case Studies, December 1993, T+120
Westerly component of wind u
ROGW2 - OP
Pressure (mBar)
100
200
300
400
500
600
700
800
900
90N 80N 70N 60N 50N 40N 30N 20N 10N 0 10S 20S 30S 40S 50S 60S 70S 80S
Latitude
Contour interval 0.5m/s
(d)
5 Case Studies, December 1993, T+120
Westerly component of wind u
ROGW2 - ROGW1
Pressure (mBar)
100
200
300
400
500
600
700
800
900
90N 80N 70N 60N 50N 40N 30N 20N 10N 0 10S 20S 30S 40S 50S 60S 70S 80S
Latitude
Contour interval 0.5m/s

Figure 3.1

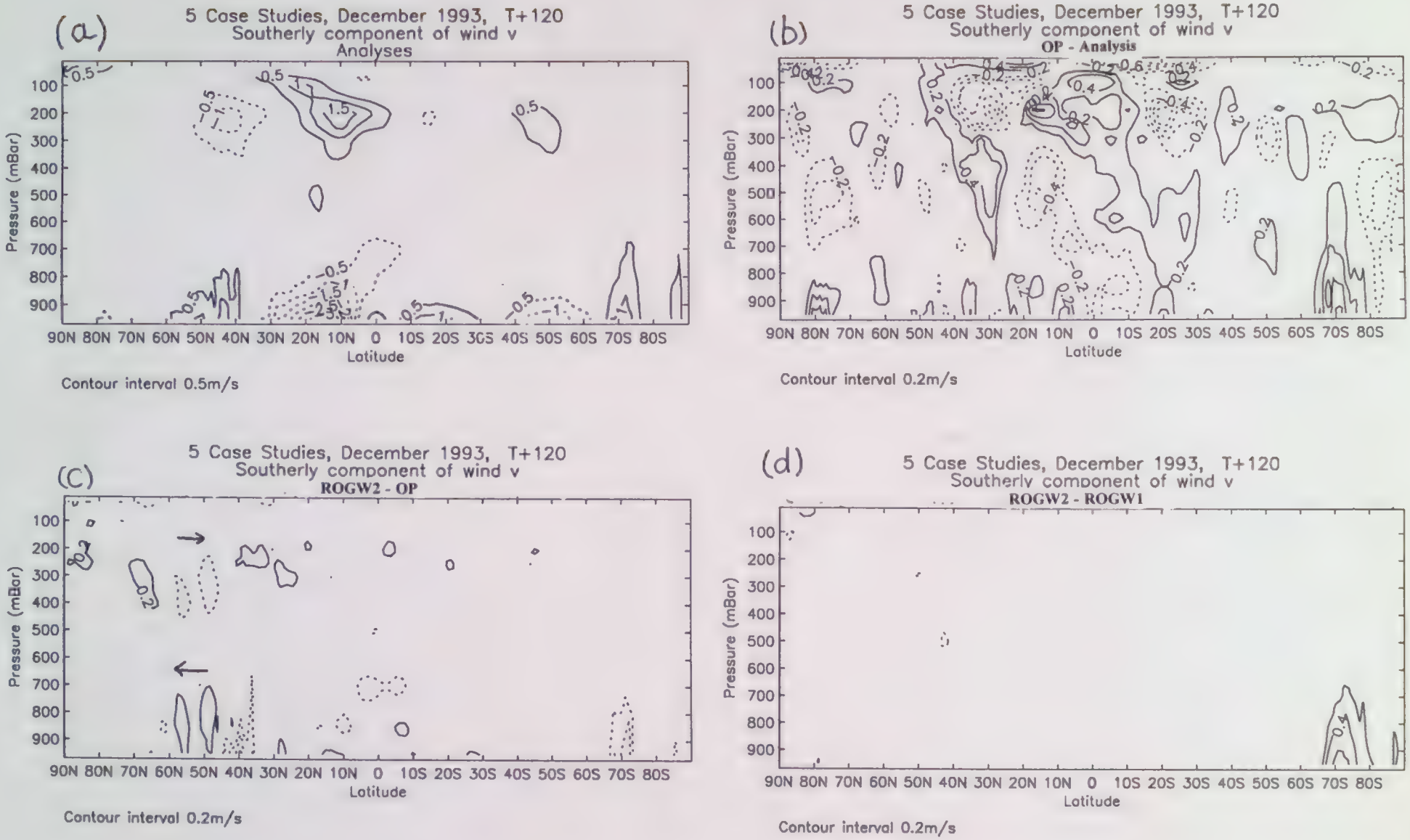
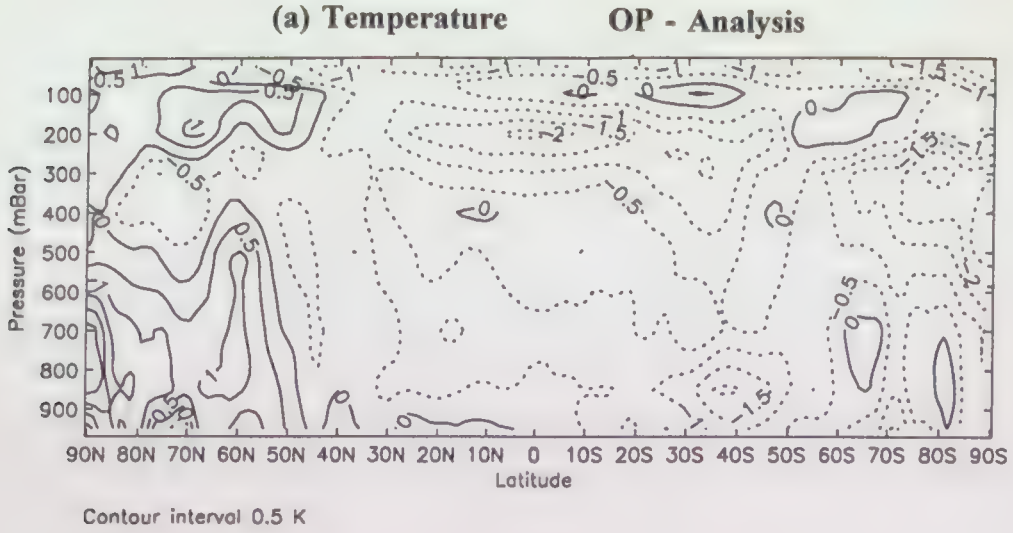
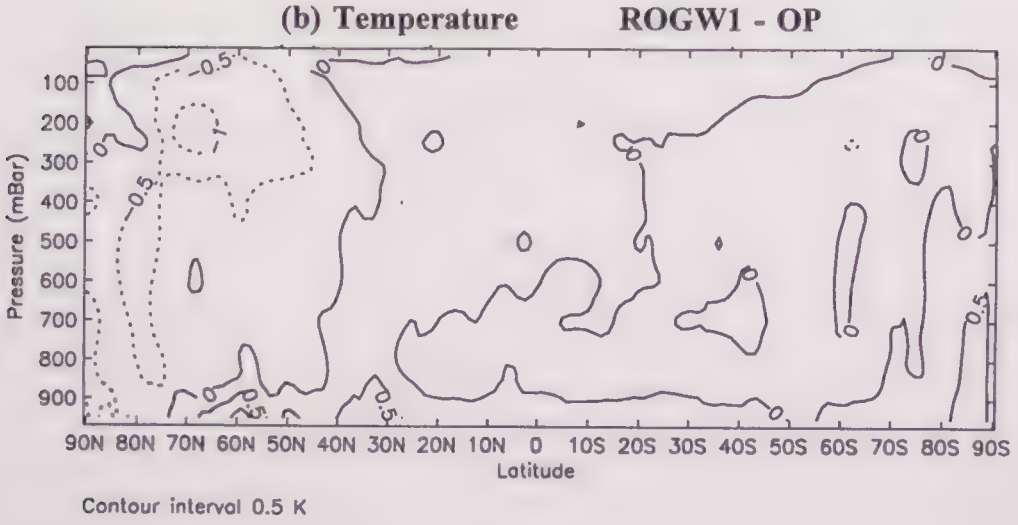

(a)
5 Case Studies, December 1993, T+120
Southerly component of wind v
Analyses
Pressure (mBar)
Latitude
90N 80N 70N 60N 50N 40N 30N 20N 10N 0 10S 20S 30S 40S 50S 60S 70S 80S
Contour interval 0.5m/s
(b)
5 Case Studies, December 1993, T+120
Southerly component of wind v
OP - Analysis
Pressure (mBar)
Latitude
90N 80N 70N 60N 50N 40N 30N 20N 10N 0 10S 20S 30S 40S 50S 60S 70S 80S
Contour interval 0.2m/s
(C)
5 Case Studies, December 1993, T+120
Southerly component of wind v
ROGW2 - OP
Pressure (mBar)
Latitude
90N 80N 70N 60N 50N 40N 30N 20N 10N 0 10S 20S 30S 40S 50S 60S 70S 80S
Contour interval 0.2m/s
(d)
5 Case Studies, December 1993, T+120
Southerly component of wind v
ROGW2 - ROGW1
Pressure (mBar)
Latitude
90N 80N 70N 60N 50N 40N 30N 20N 10N 0 10S 20S 30S 40S 50S 60S 70S 80S
Contour interval 0.2m/s

Figure 3.2


(a) Temperature OP - Analysis
Pressure (mBar)
100
200
300
400
500
600
700
800
900
90N 80N 70N 60N 50N 40N 30N 20N 10N 0 10S 20S 30S 40S 50S 60S 70S 80S 90S
Latitude
Contour interval 0.5 K


(b) Temperature ROGW1 - OP
Pressure (mBar)
100
200
300
400
500
600
700
800
900
90N 80N 70N 60N 50N 40N 30N 20N 10N 0 10S 20S 30S 40S 50S 60S 70S 80S 90S
Latitude
Contour interval 0.5 K

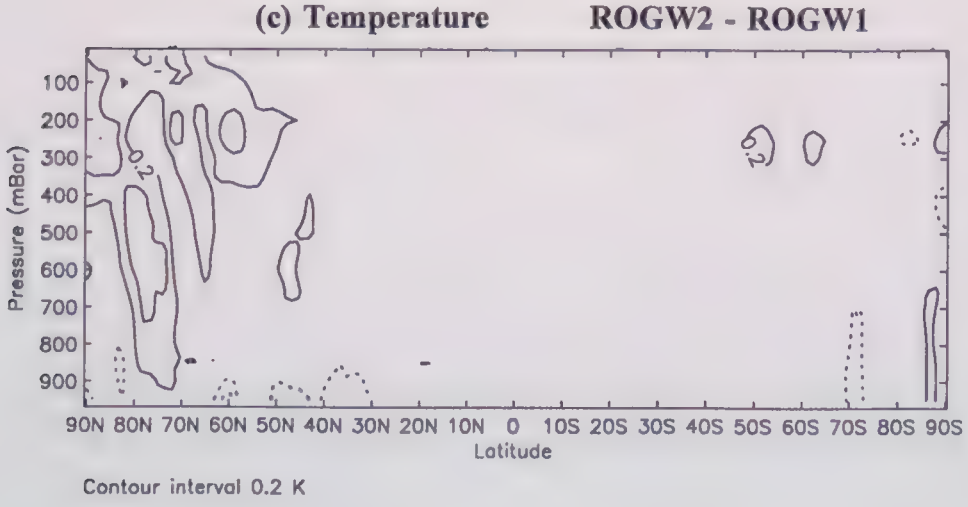

(c) Temperature ROGW2 - ROGW1
Pressure (mBar)
100
200
300
400
500
600
700
800
900
90N 80N 70N 60N 50N 40N 30N 20N 10N 0 10S 20S 30S 40S 50S 60S 70S 80S 90S
Latitude
Contour interval 0.2 K

Figure 3.3

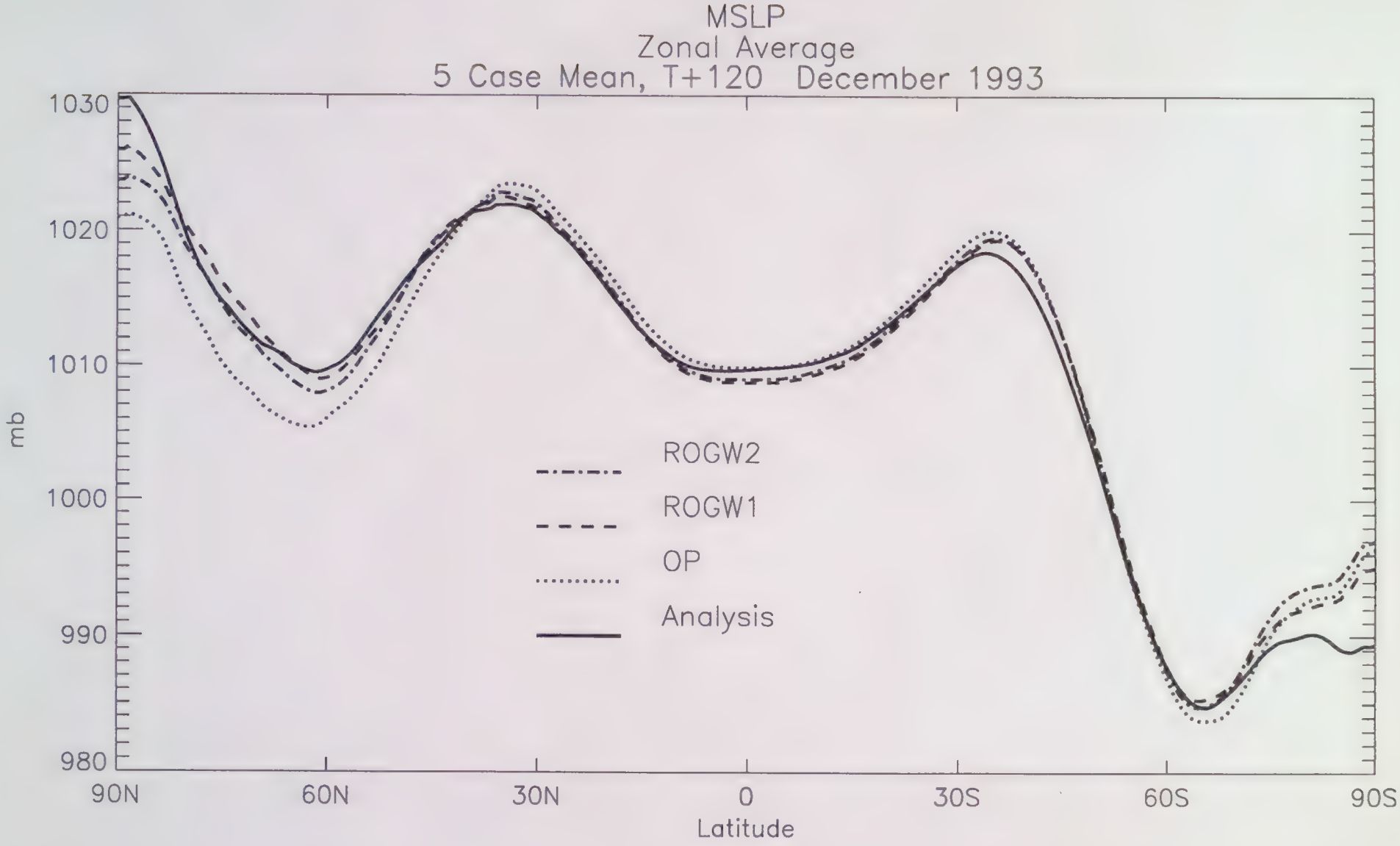

MSLP
Zonal Average
5 Case Mean, T+120 December 1993
1030
1020
1010
1000
990
980
mb
ROGW2
ROGW1
OP
Analysis
90N
60N
30N
0
30S
60S
90S
Latitude

Figure 3.4

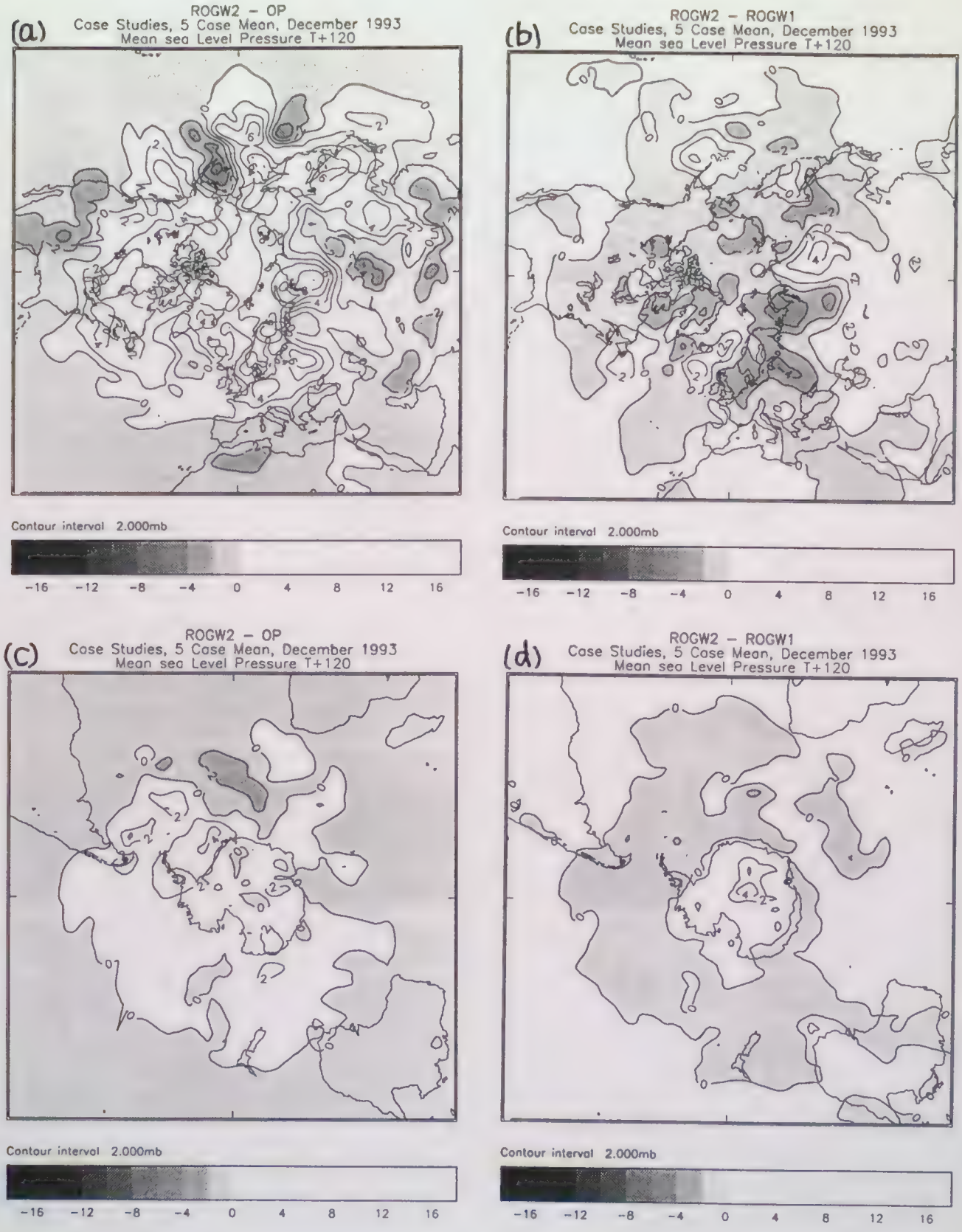

(a)
ROGW2 – OP
Case Studies, 5 Case Mean, December 1993
Mean sea Level Pressure T+120
Contour interval 2.000mb
−16 −12 −8 −4 0 4 8 12 16
(b)
ROGW2 – ROGW1
Case Studies, 5 Case Mean, December 1993
Mean sea Level Pressure T+120
Contour interval 2.000mb
−16 −12 −8 −4 0 4 8 12 16
(c)
ROGW2 – OP
Case Studies, 5 Case Mean, December 1993
Mean sea Level Pressure T+120
Contour interval 2.000mb
−16 −12 −8 −4 0 4 8 12 16
(d)
ROGW2 – ROGW1
Case Studies, 5 Case Mean, December 1993
Mean sea Level Pressure T+120
Contour interval 2.000mb
−16 −12 −8 −4 0 4 8 12 16

Figure 3.5

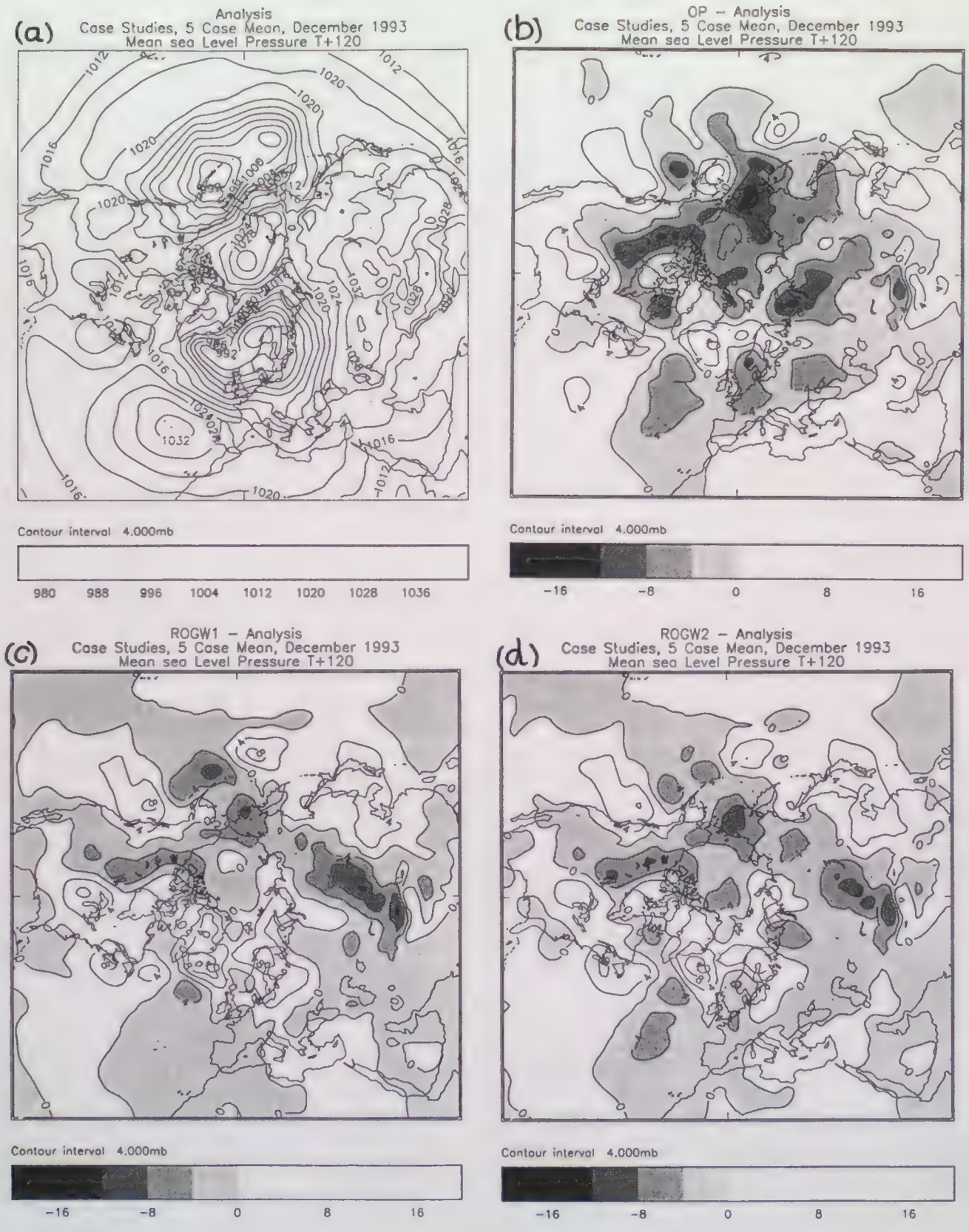

(a)
Analysis
Case Studies, 5 Case Mean, December 1993
Mean sea Level Pressure T+120
Contour interval 4.000mb
980 988 996 1004 1012 1020 1028 1036
(b)
OP – Analysis
Case Studies, 5 Case Mean, December 1993
Mean sea Level Pressure T+120
Contour interval 4.000mb
−16 −8 0 8 16
(c)
ROGW1 – Analysis
Case Studies, 5 Case Mean, December 1993
Mean sea Level Pressure T+120
Contour interval 4.000mb
−16 −8 0 8 16
(d)
ROGW2 – Analysis
Case Studies, 5 Case Mean, December 1993
Mean sea Level Pressure T+120
Contour interval 4.000mb
−16 −8 0 8 16

Figure 3.6

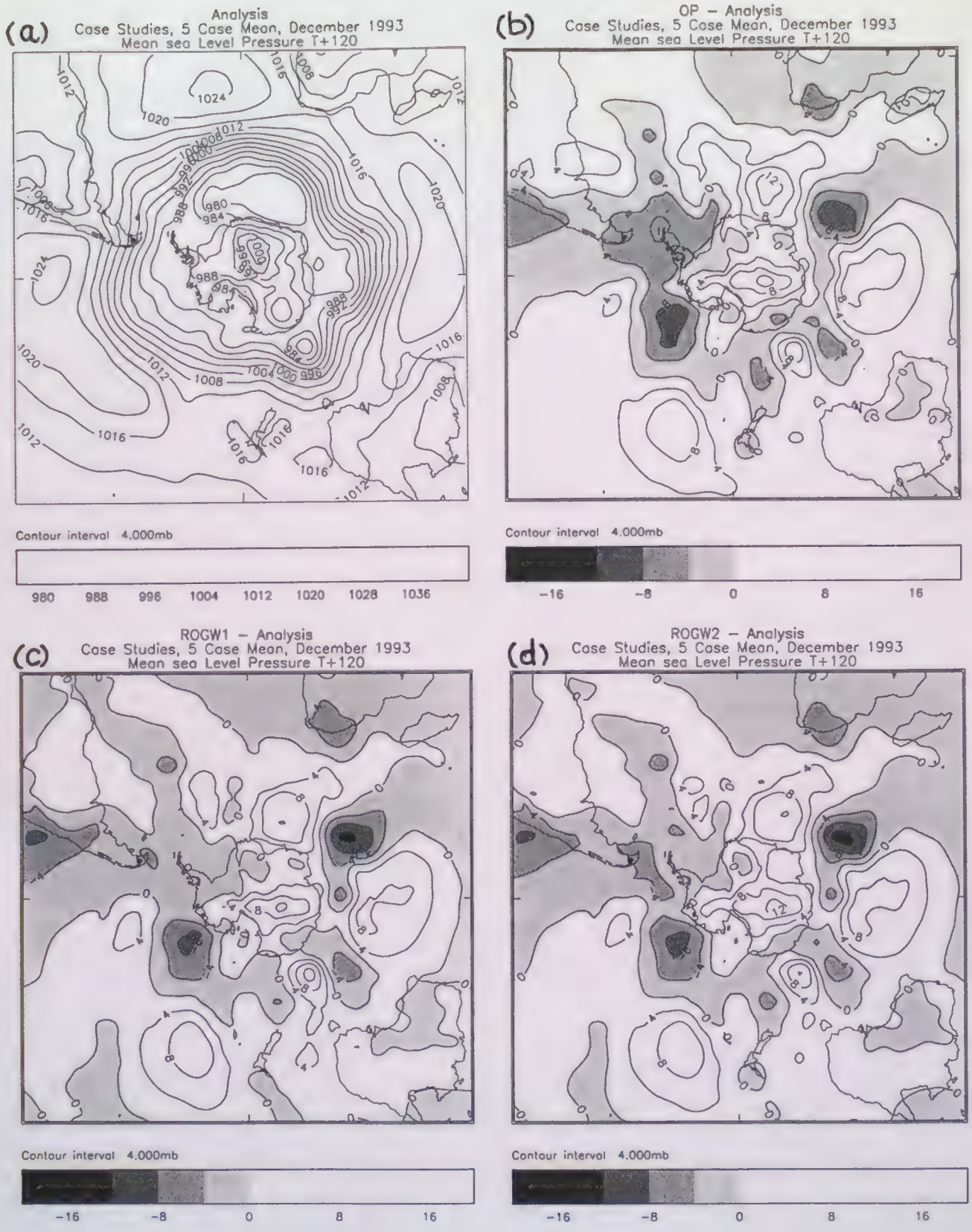

(a)
Analysis
Case Studies, 5 Case Mean, December 1993
Mean sea Level Pressure T+120
Contour interval 4.000mb
980 988 996 1004 1012 1020 1028 1036
(b)
OP – Analysis
Case Studies, 5 Case Mean, December 1993
Mean sea Level Pressure T+120
Contour interval 4.000mb
−16 −8 0 8 16
(c)
ROGW1 – Analysis
Case Studies, 5 Case Mean, December 1993
Mean sea Level Pressure T+120
Contour interval 4.000mb
−16 −8 0 8 16
(d)
ROGW2 – Analysis
Case Studies, 5 Case Mean, December 1993
Mean sea Level Pressure T+120
Contour interval 4.000mb
−16 −8 0 8 16

Figure 3.7

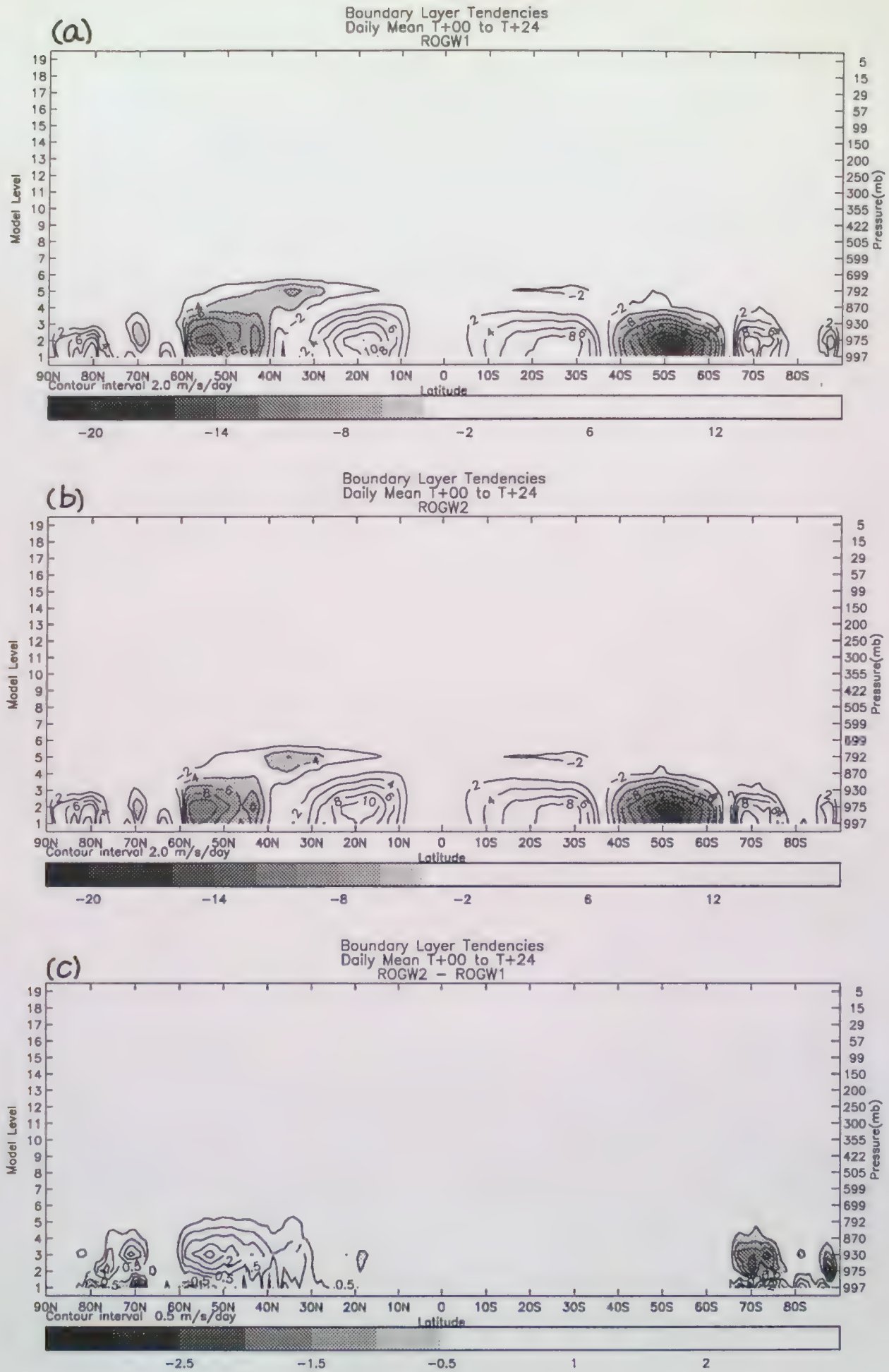

(a)
Boundary Layer Tendencies
Daily Mean T+00 to T+24
ROGW1
Model Level
Pressure(mb)
Latitude
Contour interval 2.0 m/s/day
(b)
Boundary Layer Tendencies
Daily Mean T+00 to T+24
ROGW2
Model Level
Pressure(mb)
Latitude
Contour interval 2.0 m/s/day
(c)
Boundary Layer Tendencies
Daily Mean T+00 to T+24
ROGW2 - ROGW1
Model Level
Pressure(mb)
Latitude
Contour interval 0.5 m/s/day

Figure 3.8

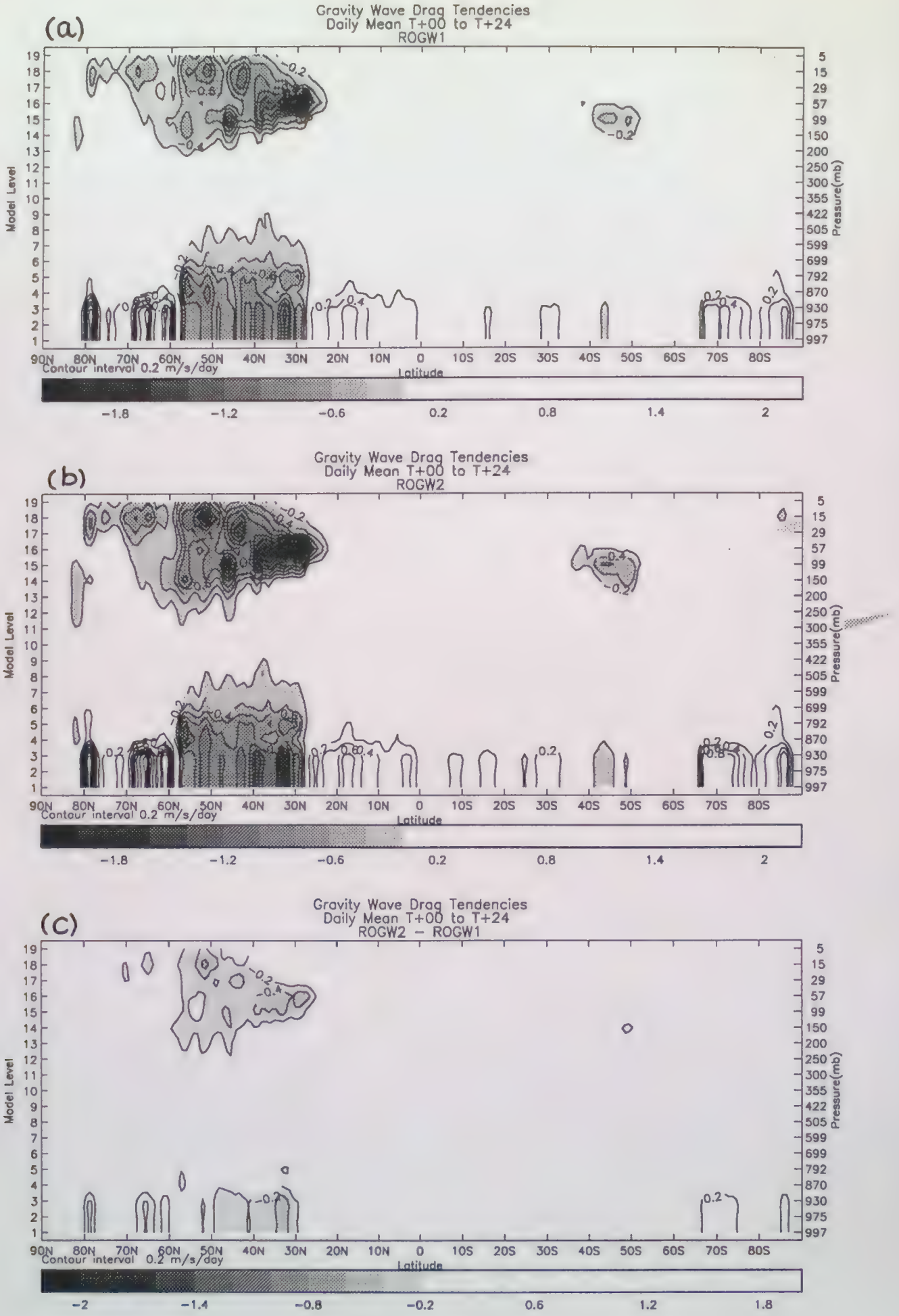
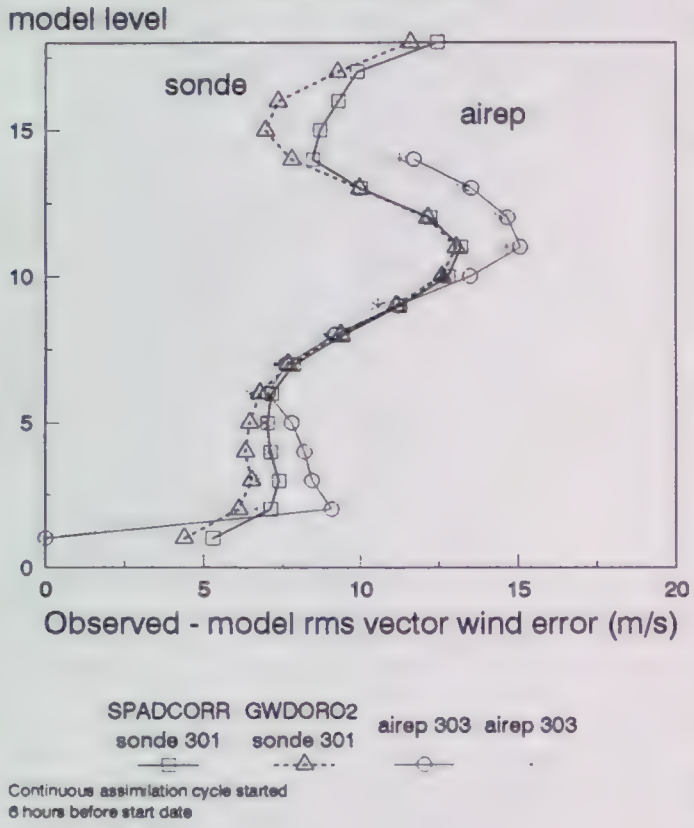
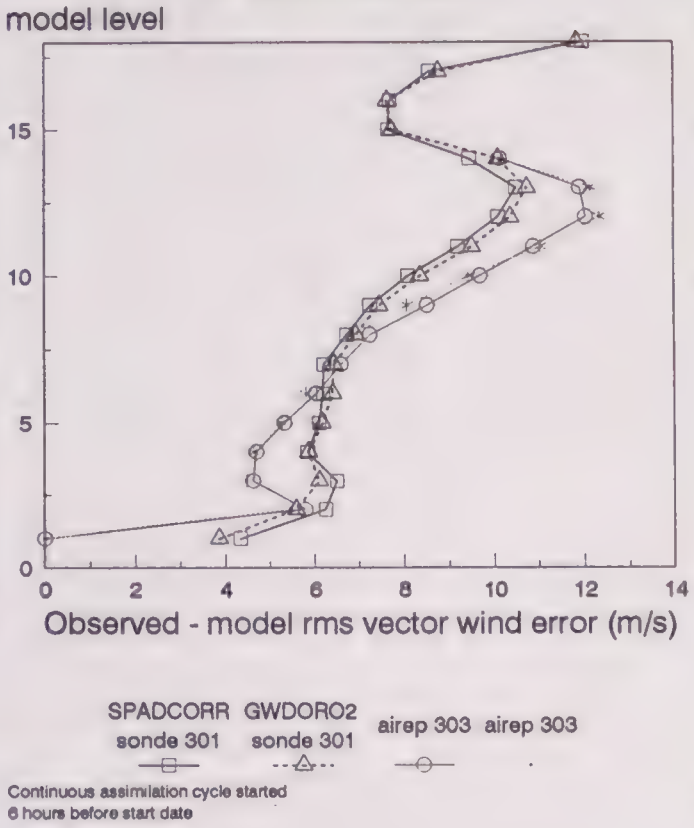

(a)
Gravity Wave Drag Tendencies
Daily Mean T+00 to T+24
ROGW1
(b)
Gravity Wave Drag Tendencies
Daily Mean T+00 to T+24
ROGW2
(c)
Gravity Wave Drag Tendencies
Daily Mean T+00 to T+24
ROGW2 – ROGW1
Model Level
Pressure(mb)
Latitude
90N 80N 70N 60N 50N 40N 30N 20N 10N 0 10S 20S 30S 40S 50S 60S 70S 80S
Contour interval 0.2 m/s/day
-1.8 -1.2 -0.6 0.2 0.8 1.4 2
-2 -1.4 -0.8 -0.2 0.6 1.2 1.8

Figure 3.9

(a)



(b)



(c)

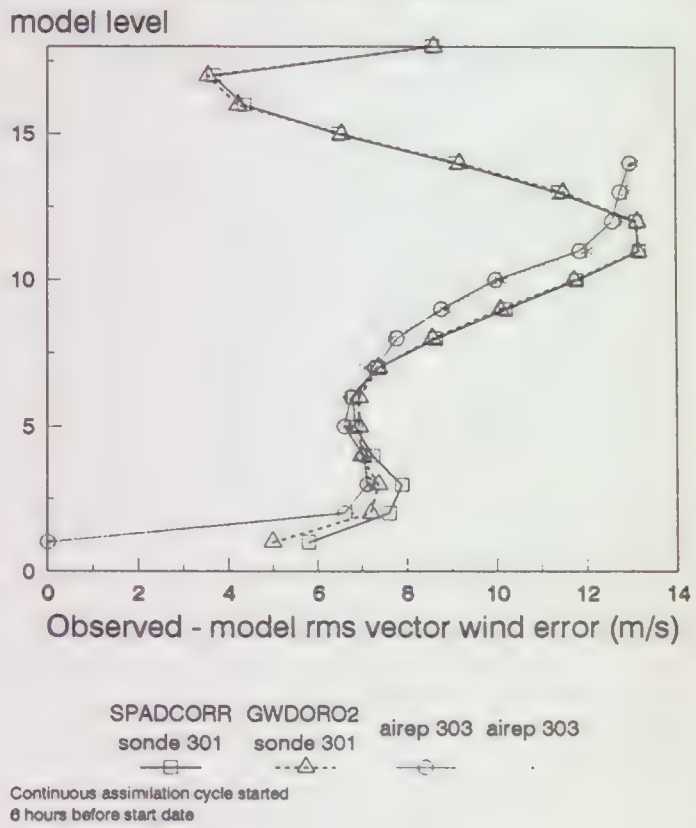


Figure 3.10

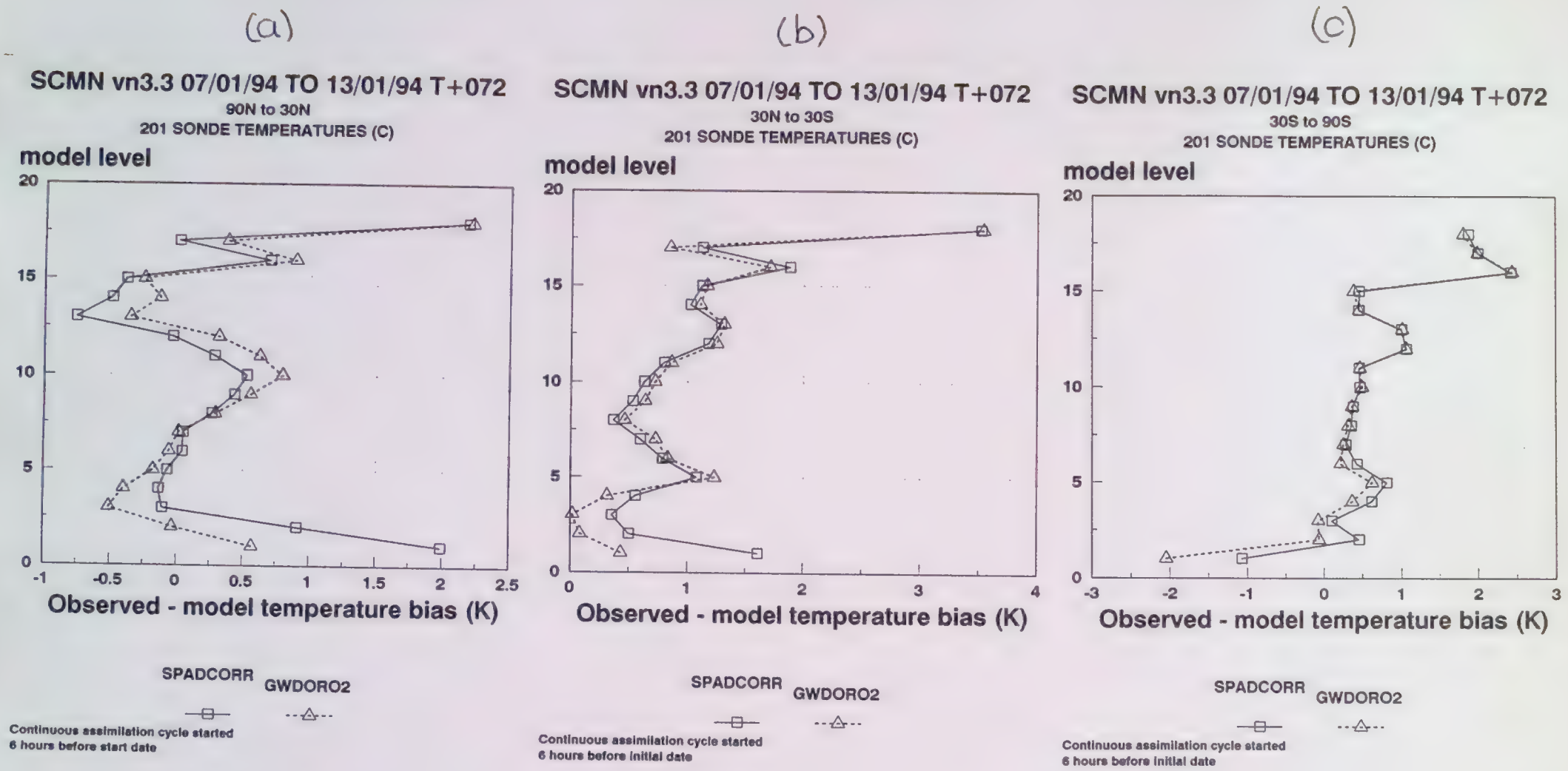
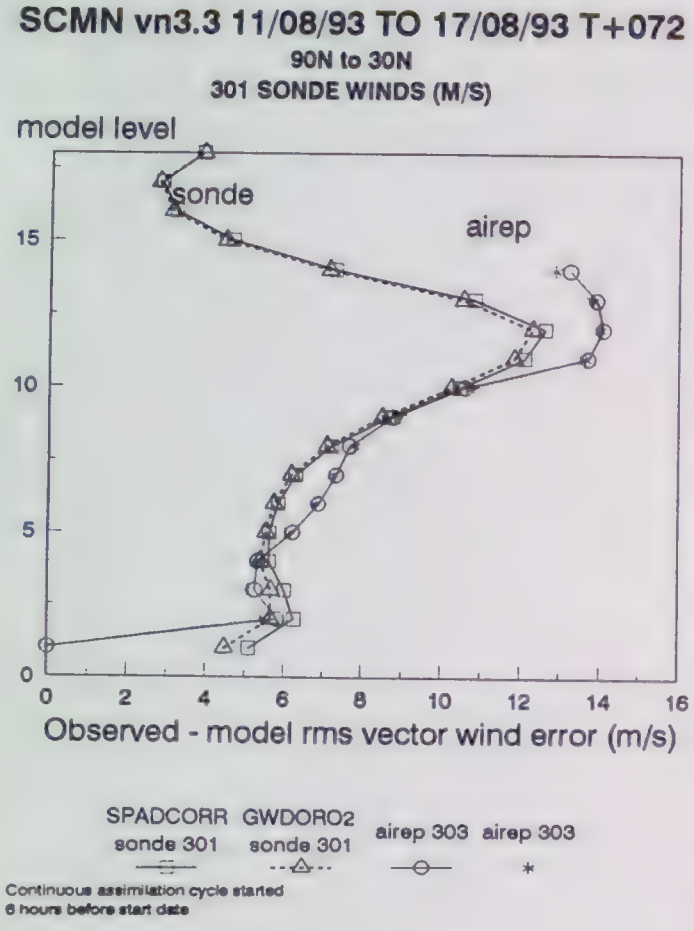
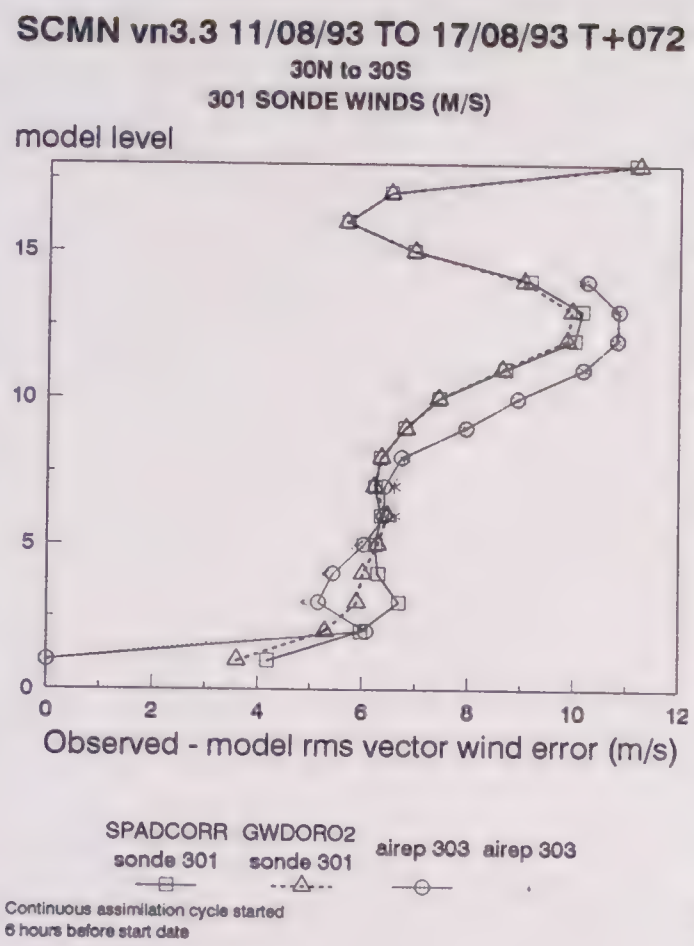

(a)
SCMN vn3.3 07/01/94 TO 13/01/94 T+072
90N to 30N
201 SONDE TEMPERATURES (C)
model level
Observed - model temperature bias (K)
SPADCORR
GWDORO2
Continuous assimilation cycle started
6 hours before start date
(b)
SCMN vn3.3 07/01/94 TO 13/01/94 T+072
30N to 30S
201 SONDE TEMPERATURES (C)
model level
Observed - model temperature bias (K)
SPADCORR
GWDORO2
Continuous assimilation cycle started
6 hours before initial date
(c)
SCMN vn3.3 07/01/94 TO 13/01/94 T+072
30S to 90S
201 SONDE TEMPERATURES (C)
model level
Observed - model temperature bias (K)
SPADCORR
GWDORO2
Continuous assimilation cycle started
6 hours before initial date

Figure 3.11

(a)



(b)



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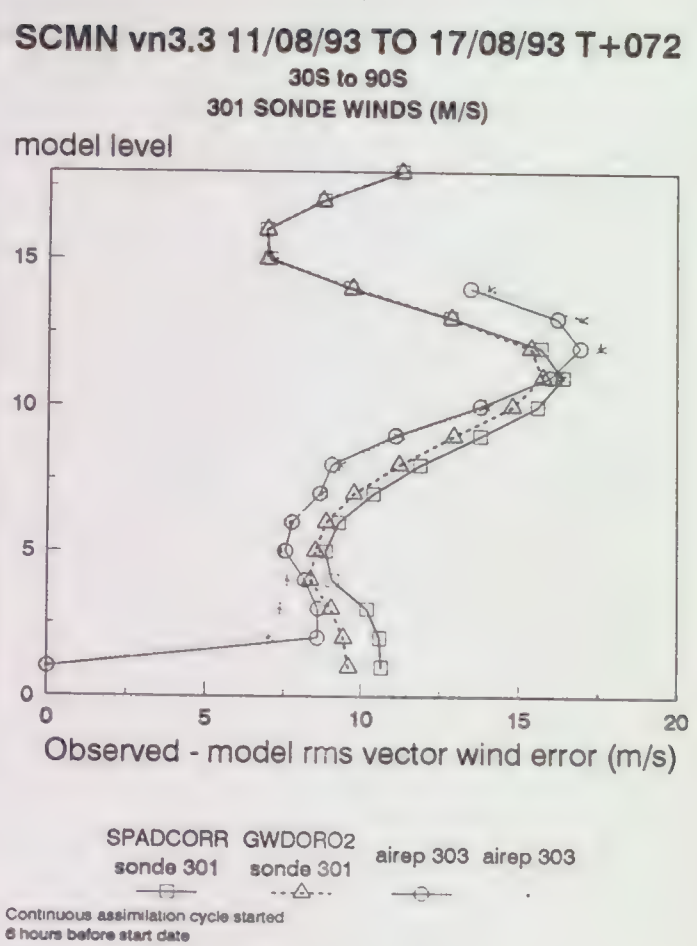
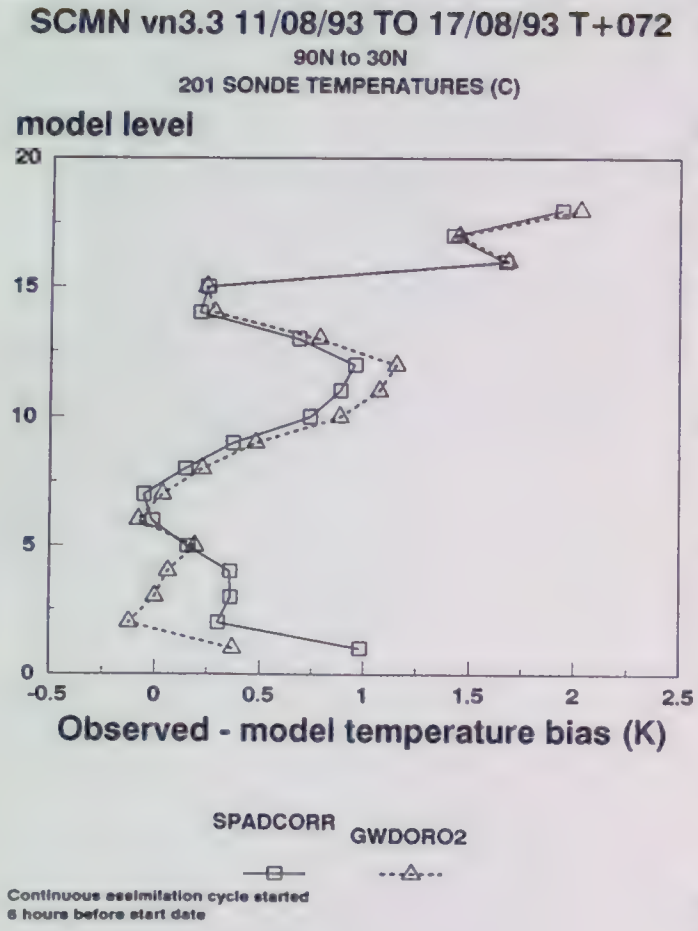
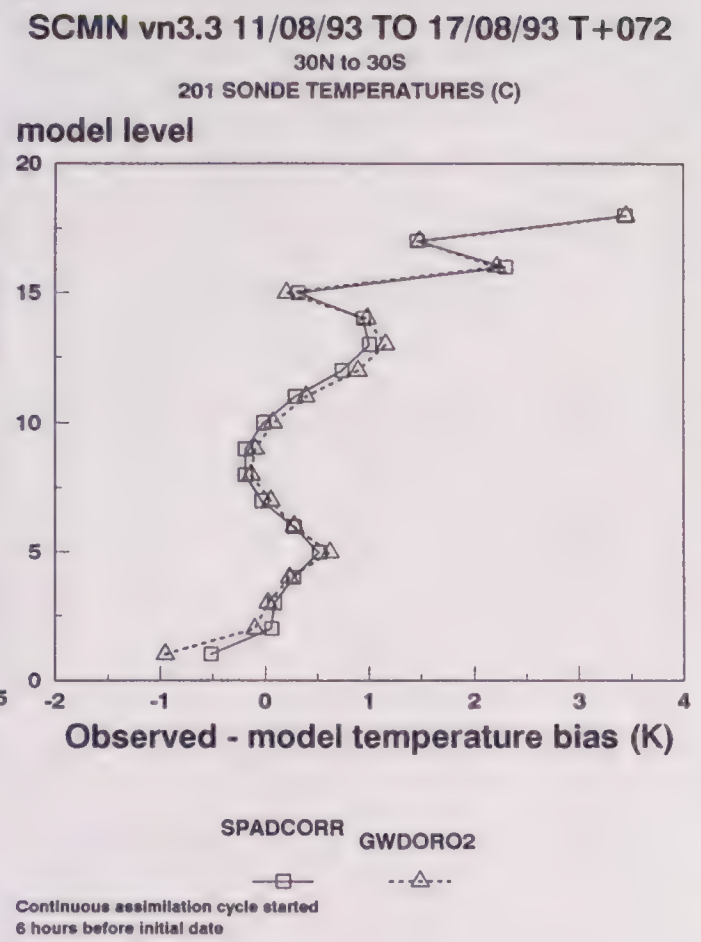


Figure 3.12

(a)



(b)



(c)

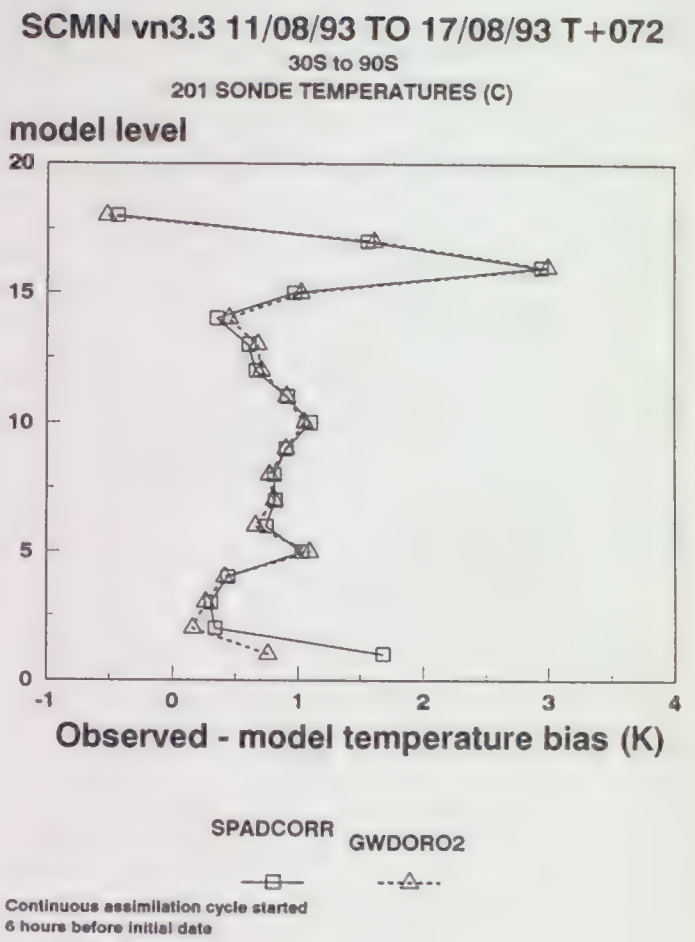


Figure 3.13

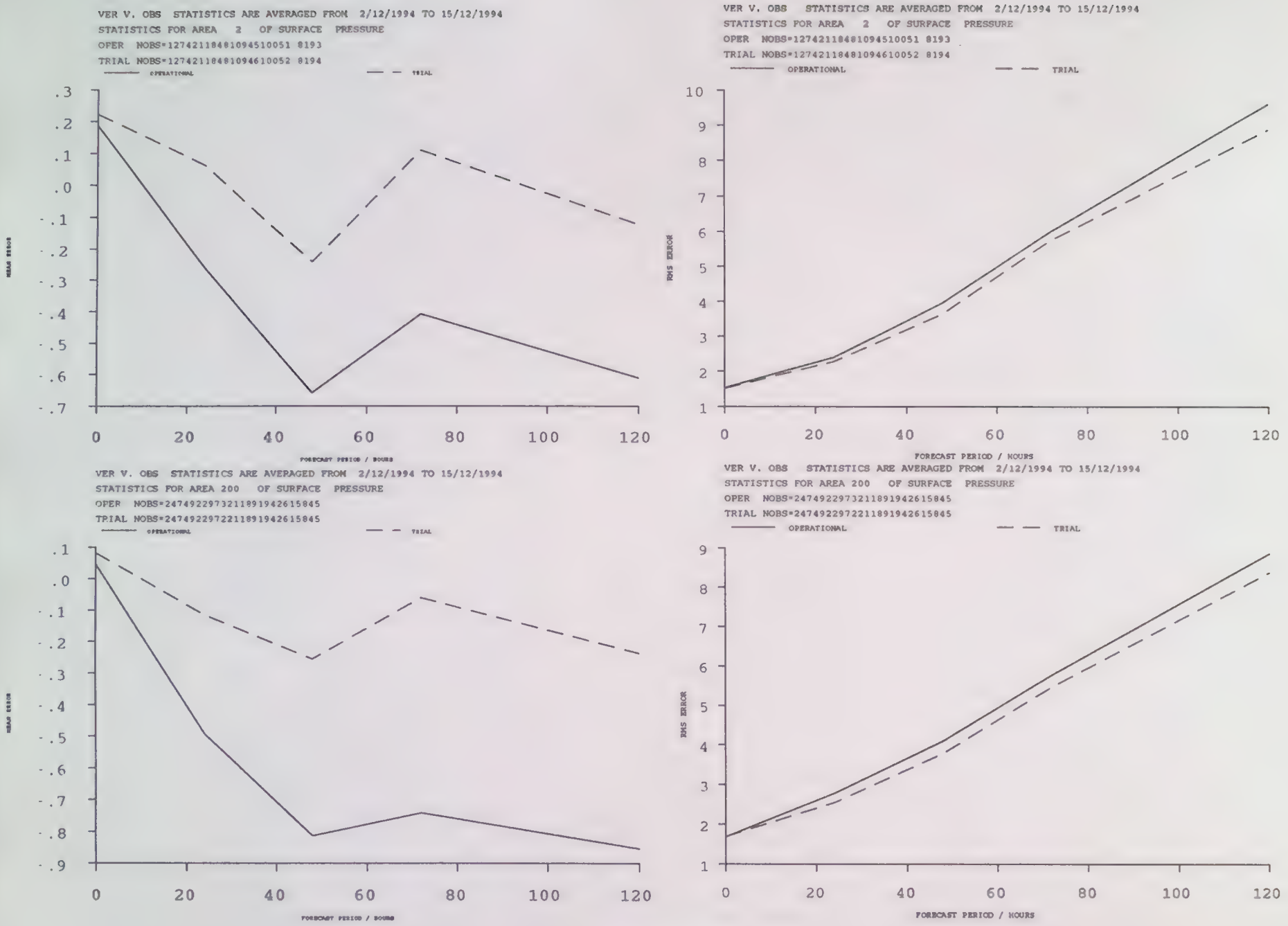

VER V. OBS STATISTICS ARE AVERAGED FROM 2/12/1994 TO 15/12/1994
STATISTICS FOR AREA 2 OF SURFACE PRESSURE
OPER NOBS=1274211848109451005l 8193
TRIAL NOBS=1274211848109461005l 8194
OPERATIONAL
TRIAL
MEAN ERROR
FORECAST PERIOD / HOURS
VER V. OBS STATISTICS ARE AVERAGED FROM 2/12/1994 TO 15/12/1994
STATISTICS FOR AREA 2 OF SURFACE PRESSURE
OPER NOBS=1274211848109451005l 8193
TRIAL NOBS=1274211848109461005l 8194
OPERATIONAL
TRIAL
RMS ERROR
FORECAST PERIOD / HOURS
VER V. OBS STATISTICS ARE AVERAGED FROM 2/12/1994 TO 15/12/1994
STATISTICS FOR AREA 200 OF SURFACE PRESSURE
OPER NOBS=247492297321189194261584 5
TRIAL NOBS=247492297221189194261584 5
OPERATIONAL
TRIAL
MEAN ERROR
FORECAST PERIOD / HOURS
VER V. OBS STATISTICS ARE AVERAGED FROM 2/12/1994 TO 15/12/1994
STATISTICS FOR AREA 200 OF SURFACE PRESSURE
OPER NOBS=247492297321189194261584 5
TRIAL NOBS=247492297221189194261584 5
OPERATIONAL
TRIAL
RMS ERROR
FORECAST PERIOD / HOURS

FIGURE 4.1

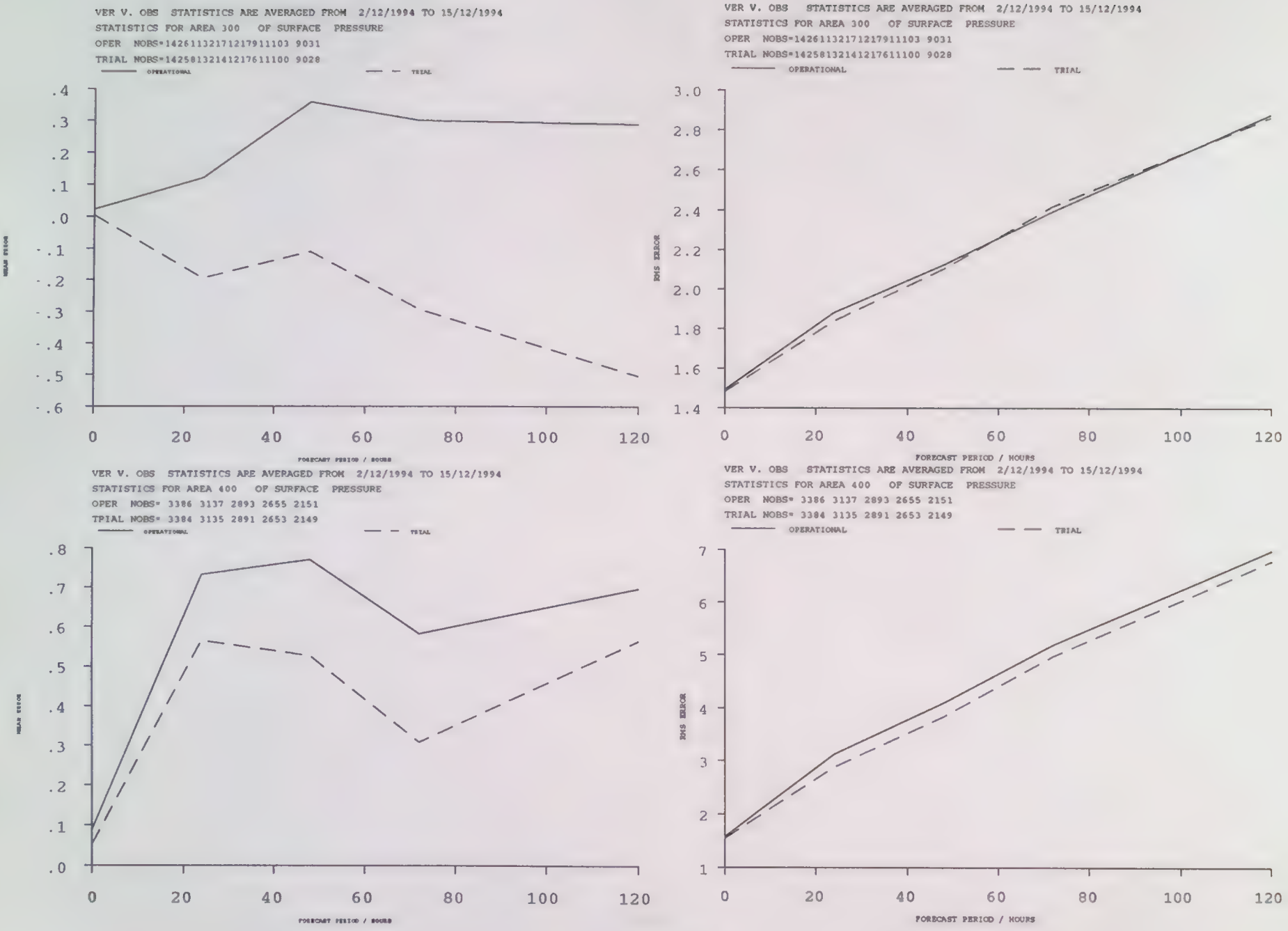
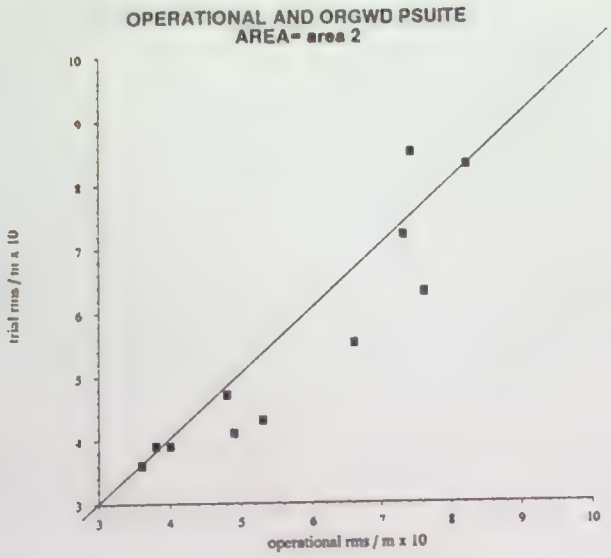
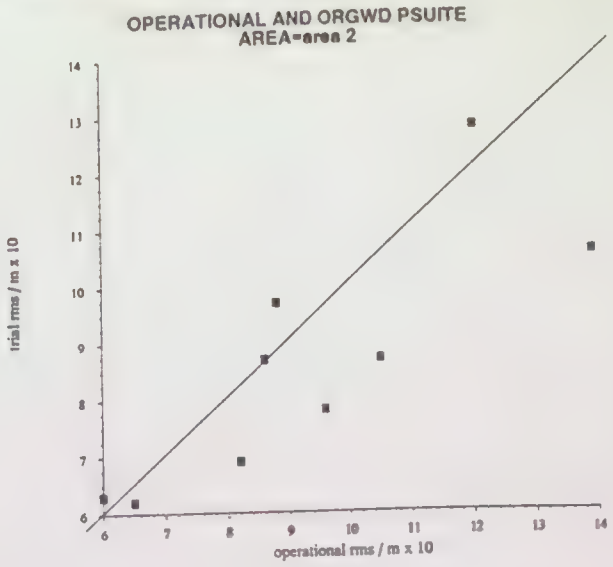

VER V. OBS STATISTICS ARE AVERAGED FROM 2/12/1994 TO 15/12/1994
STATISTICS FOR AREA 300 OF SURFACE PRESSURE
OPER NOBS=14261132171217911103 9031
TRIAL NOBS=14258132141217611100 9028
OPERATIONAL
TRIAL
MEAN ERROR
.4
.3
.2
.1
.0
-.1
-.2
-.3
-.4
-.5
-.6
0
20
40
60
80
100
120
FORECAST PERIOD / HOURS
VER V. OBS STATISTICS ARE AVERAGED FROM 2/12/1994 TO 15/12/1994
STATISTICS FOR AREA 300 OF SURFACE PRESSURE
OPER NOBS=14261132171217911103 9031
TRIAL NOBS=14258132141217611100 9028
OPERATIONAL
TRIAL
RMS ERROR
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
0
20
40
60
80
100
120
FORECAST PERIOD / HOURS
VER V. OBS STATISTICS ARE AVERAGED FROM 2/12/1994 TO 15/12/1994
STATISTICS FOR AREA 400 OF SURFACE PRESSURE
OPER NOBS= 3386 3137 2893 2655 2151
TPIAL NOBS= 3384 3135 2891 2653 2149
OPERATIONAL
TRIAL
MEAN ERROR
.8
.7
.6
.5
.4
.3
.2
.1
.0
0
20
40
60
80
100
120
FORECAST PERIOD / HOURS
VER V. OBS STATISTICS ARE AVERAGED FROM 2/12/1994 TO 15/12/1994
STATISTICS FOR AREA 400 OF SURFACE PRESSURE
OPER NOBS= 3386 3137 2893 2655 2151
TRIAL NOBS= 3384 3135 2891 2653 2149
OPERATIONAL
TRIAL
RMS ERROR
7
6
5
4
3
2
1
0
20
40
60
80
100
120
FORECAST PERIOD / HOURS

FIGURE 4.2

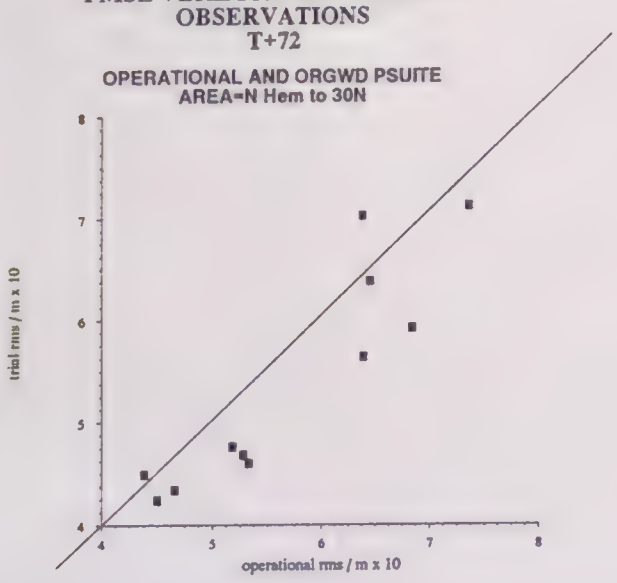
PMSL VERIFICATION AGAINST OBSERVATIONS
T+72



PMSL VERIFICATION AGAINST OBSERVATIONS
T+120



PMSL VERIFICATION AGAINST OBSERVATIONS
T+72



PMSL VERIFICATION AGAINST OBSERVATIONS
T+120

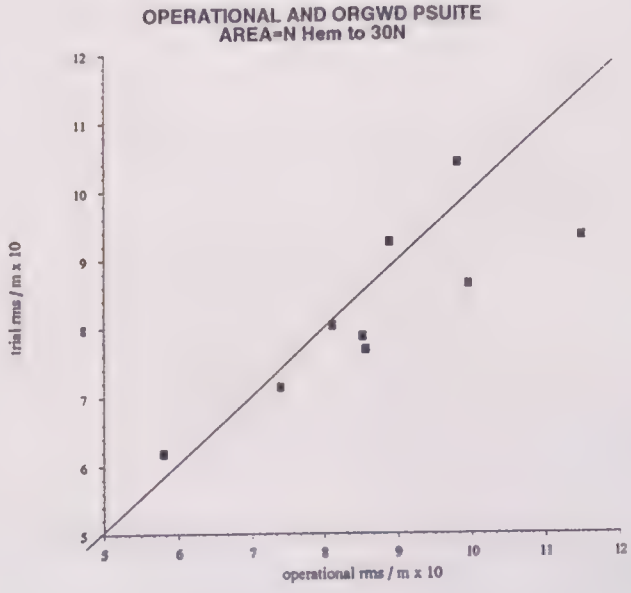
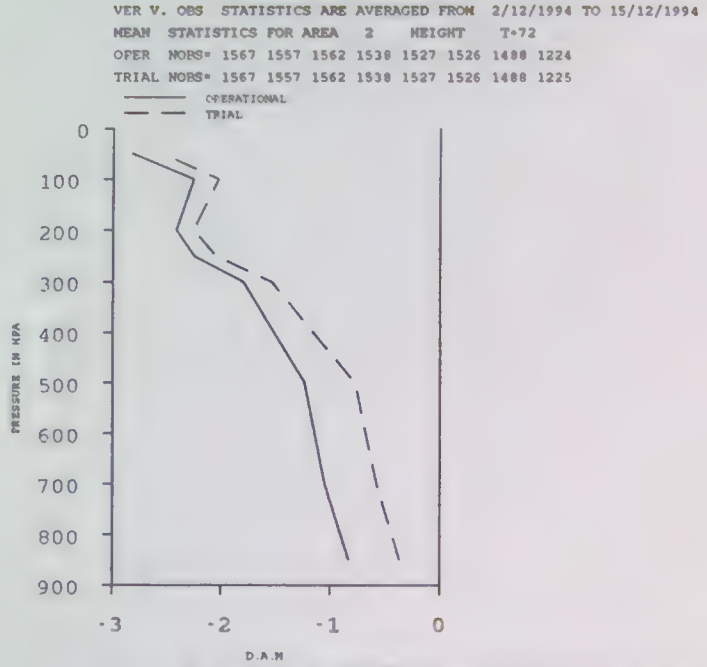
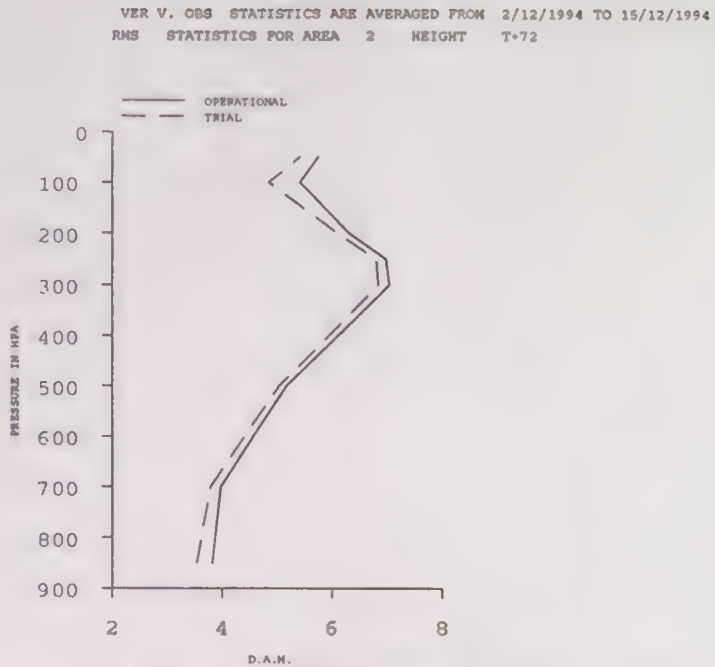
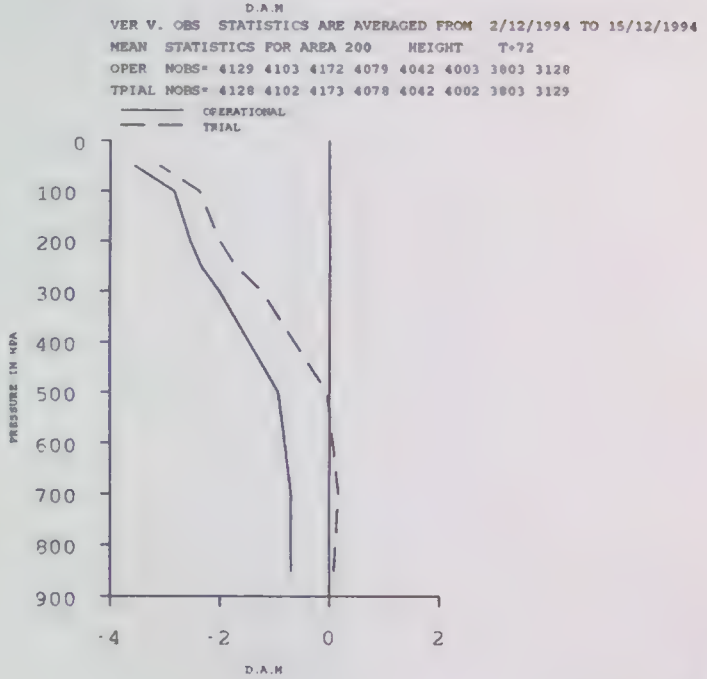


FIGURE 4.3


VER V. OBS STATISTICS ARE AVERAGED FROM 2/12/1994 TO 15/12/1994
MEAN STATISTICS FOR AREA 2 HEIGHT T+72
OPER NOBS= 1567 1557 1562 1538 1527 1526 1488 1224
TRIAL NOBS= 1567 1557 1562 1538 1527 1526 1488 1225
OPERATIONAL
TRIAL
PRESSURE IN HPA
0
100
200
300
400
500
600
700
800
900
-3
-2
-1
0
D.A.M


VER V. OBS STATISTICS ARE AVERAGED FROM 2/12/1994 TO 15/12/1994
RMS STATISTICS FOR AREA 2 HEIGHT T+72
OPERATIONAL
TRIAL
PRESSURE IN HPA
0
100
200
300
400
500
600
700
800
900
2
4
6
8
D.A.M.


VER V. OBS STATISTICS ARE AVERAGED FROM 2/12/1994 TO 15/12/1994
MEAN STATISTICS FOR AREA 200 HEIGHT T+72
OPER NOBS= 4129 4103 4172 4079 4042 4003 3803 3128
TRIAL NOBS= 4128 4102 4173 4078 4042 4002 3803 3129
OPERATIONAL
TRIAL
PRESSURE IN HPA
0
100
200
300
400
500
600
700
800
900
-4
-2
0
2
D.A.M

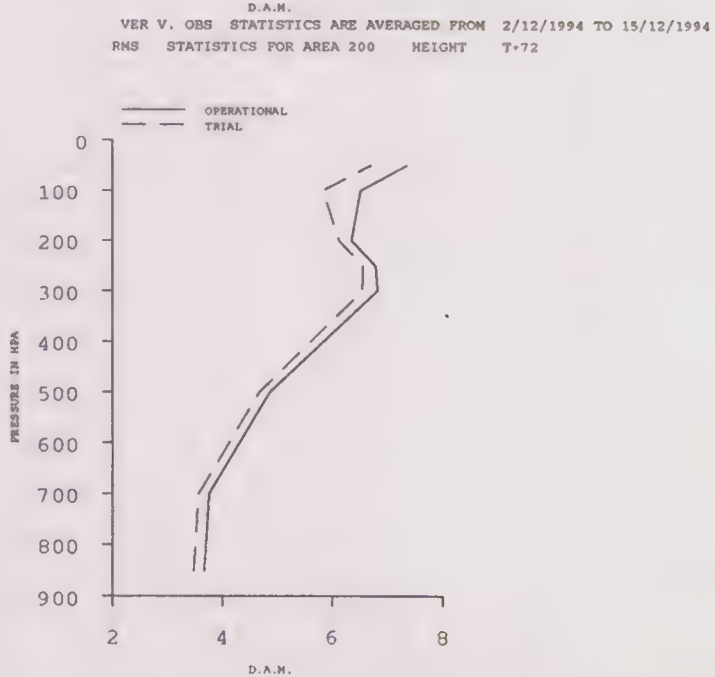
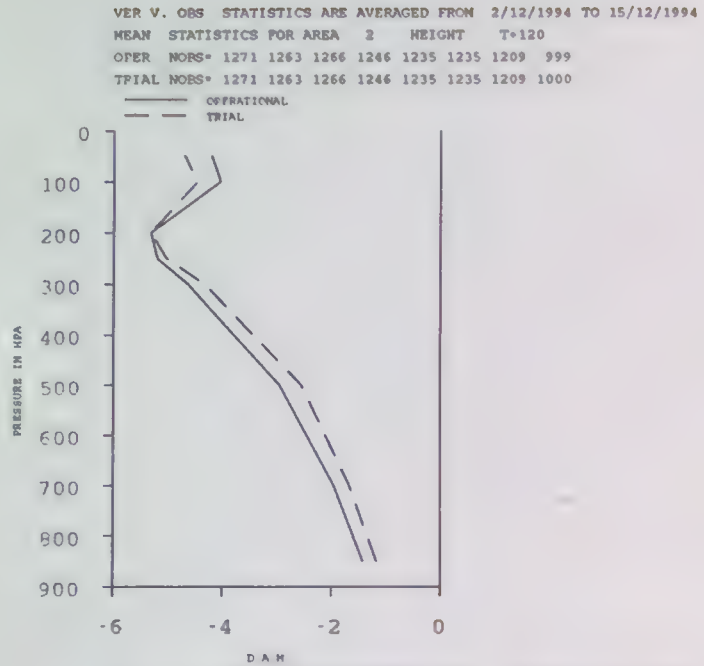
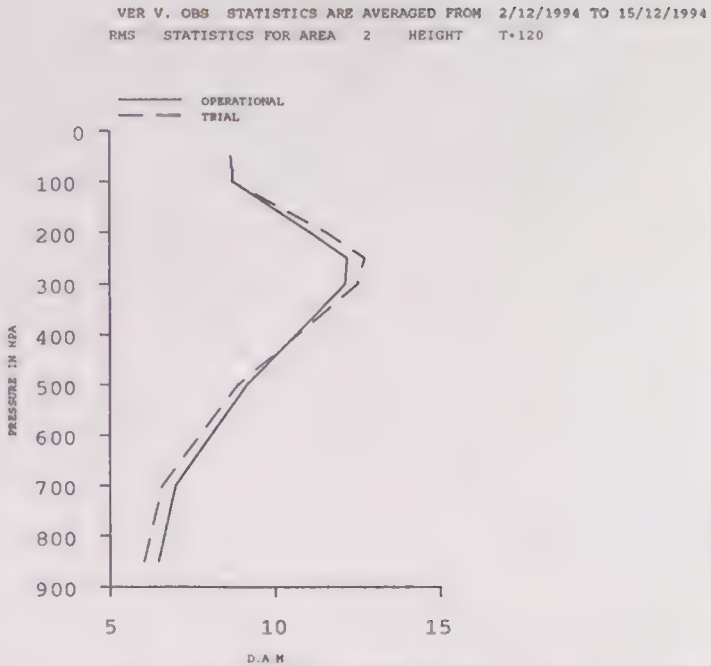
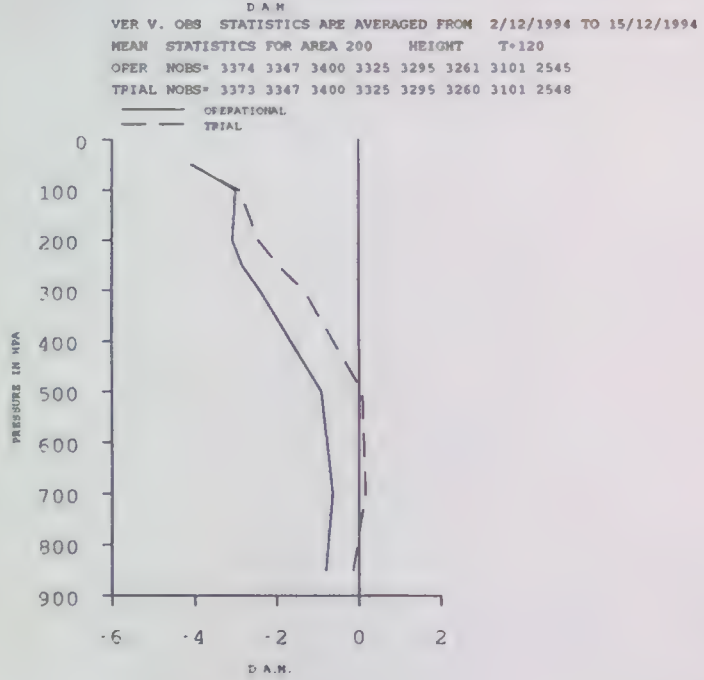

VER V. OBS STATISTICS ARE AVERAGED FROM 2/12/1994 TO 15/12/1994
RMS STATISTICS FOR AREA 200 HEIGHT T+72
OPERATIONAL
TRIAL
PRESSURE IN HPA
0
100
200
300
400
500
600
700
800
900
2
4
6
8
D.A.M.

FIGURE 4.4


VER V. OBS STATISTICS ARE AVERAGED FROM 2/12/1994 TO 15/12/1994
MEAN STATISTICS FOR AREA 2 HEIGHT T+120
OPER NOBS= 1271 1263 1266 1246 1235 1235 1209 999
TRIAL NOBS= 1271 1263 1266 1246 1235 1235 1209 1000
OPERATIONAL
TRIAL
PRESSURE IN HPA
0
100
200
300
400
500
600
700
800
900
-6
-4
-2
0
D A M


VER V. OBS STATISTICS ARE AVERAGED FROM 2/12/1994 TO 15/12/1994
RMS STATISTICS FOR AREA 2 HEIGHT T+120
OPERATIONAL
TRIAL
PRESSURE IN HPA
0
100
200
300
400
500
600
700
800
900
5
10
15
D.A.M


VER V. OBS STATISTICS ARE AVERAGED FROM 2/12/1994 TO 15/12/1994
MEAN STATISTICS FOR AREA 200 HEIGHT T+120
OPER NOBS= 3374 3347 3400 3325 3295 3261 3101 2545
TRIAL NOBS= 3373 3347 3400 3325 3295 3260 3101 2548
OPERATIONAL
TRIAL
PRESSURE IN HPA
0
100
200
300
400
500
600
700
800
900
-6
-4
-2
0
2
D A M.

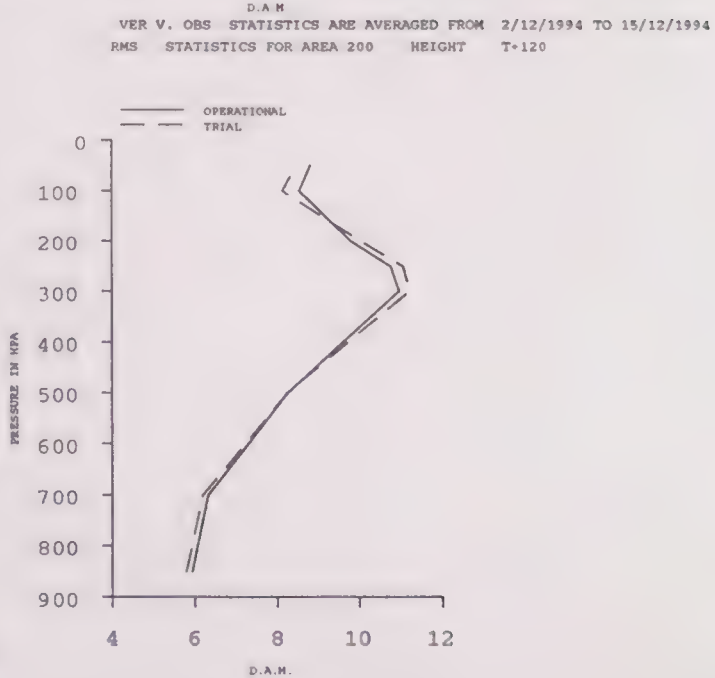
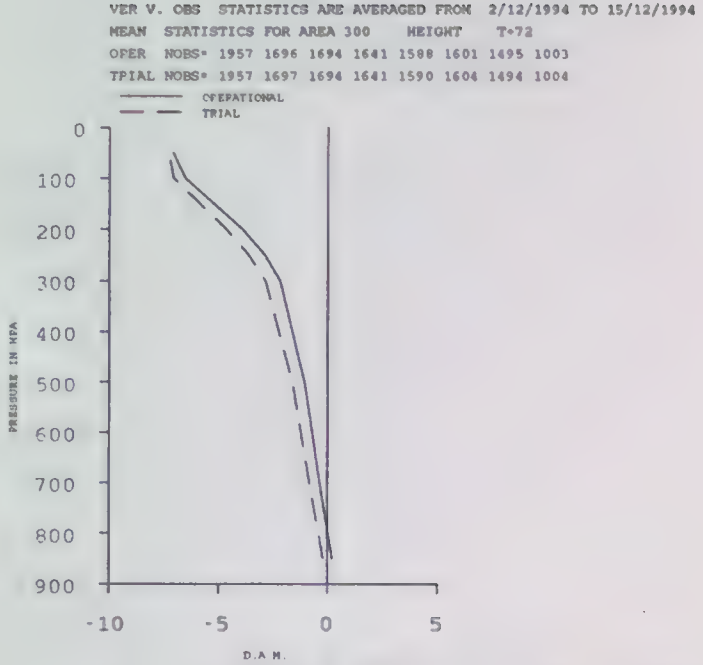
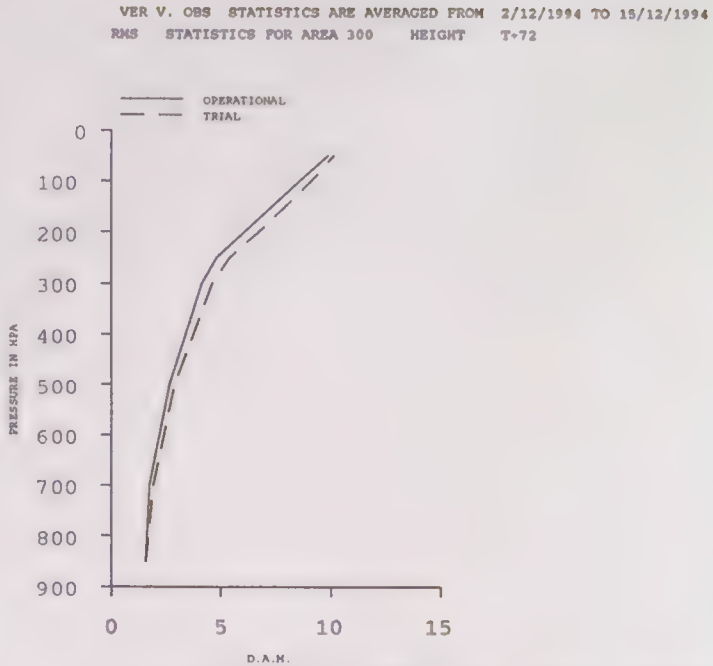
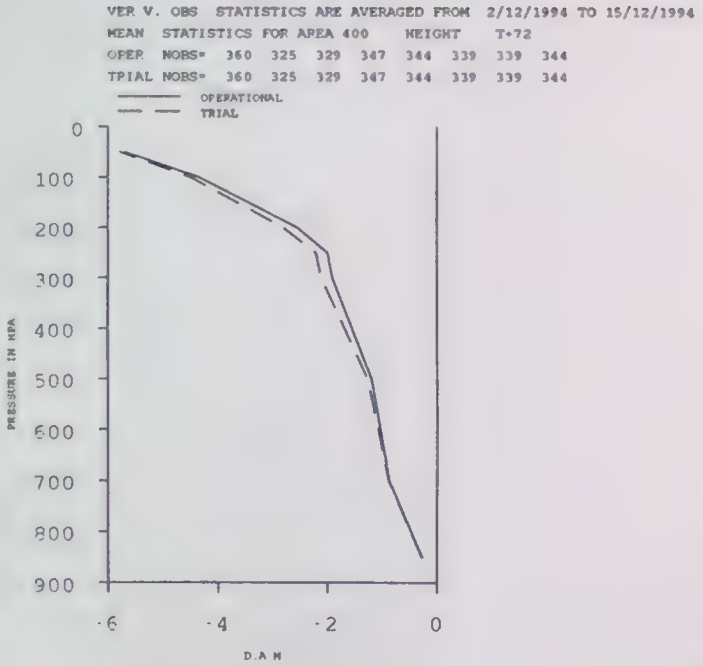

VER V. OBS STATISTICS ARE AVERAGED FROM 2/12/1994 TO 15/12/1994
RMS STATISTICS FOR AREA 200 HEIGHT T+120
OPERATIONAL
TRIAL
PRESSURE IN HPA
0
100
200
300
400
500
600
700
800
900
4
6
8
10
12
D.A.M.

FIGURE 4.5


VER V. OBS STATISTICS ARE AVERAGED FROM 2/12/1994 TO 15/12/1994
MEAN STATISTICS FOR AREA 300 HEIGHT T+72
OPER NOBS= 1957 1696 1694 1641 1598 1601 1495 1003
TRIAL NOBS= 1957 1697 1694 1641 1590 1604 1494 1004
OPERATIONAL
TRIAL
PRESSURE IN HPA
D.A.M.


VER V. OBS STATISTICS ARE AVERAGED FROM 2/12/1994 TO 15/12/1994
RMS STATISTICS FOR AREA 300 HEIGHT T+72
OPERATIONAL
TRIAL
PRESSURE IN HPA
D.A.M.


VER V. OBS STATISTICS ARE AVERAGED FROM 2/12/1994 TO 15/12/1994
MEAN STATISTICS FOR AREA 400 HEIGHT T+72
OPER NOBS= 360 325 329 347 344 339 339 344
TRIAL NOBS= 360 325 329 347 344 339 339 344
OPERATIONAL
TRIAL
PRESSURE IN HPA
D.A.M.

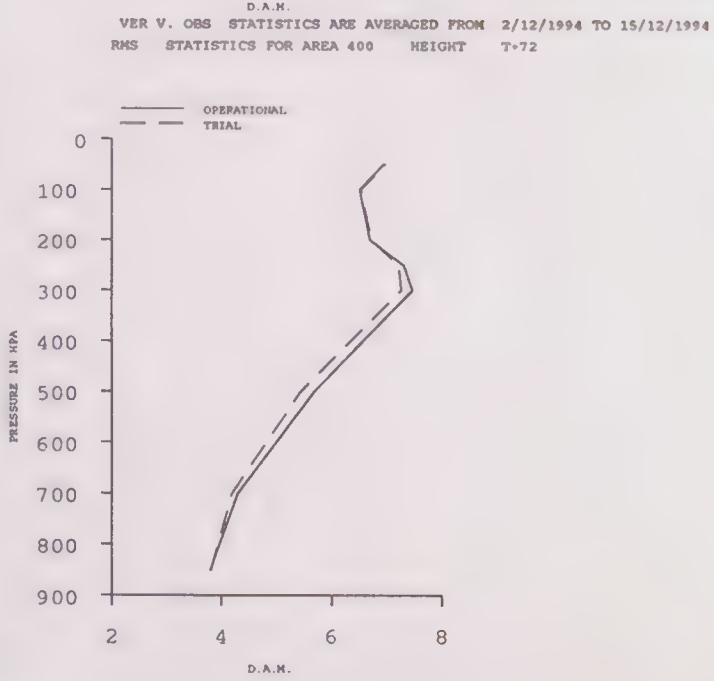
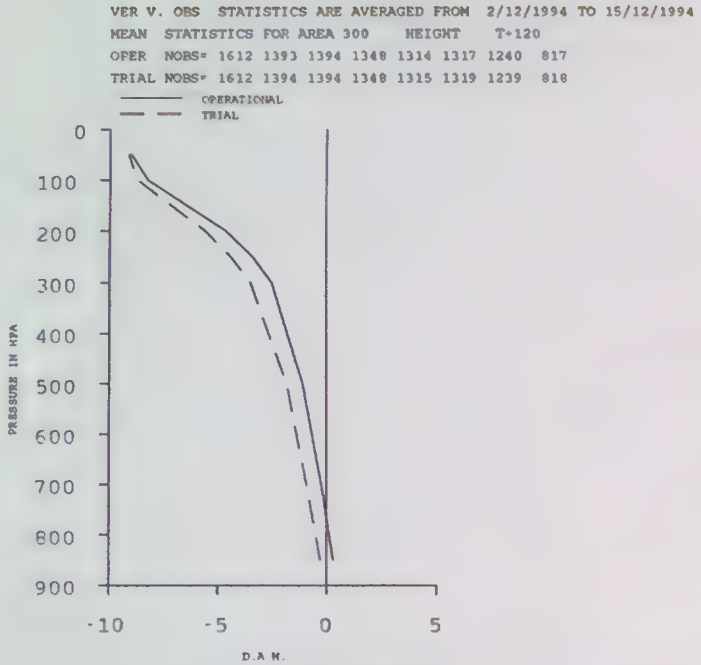
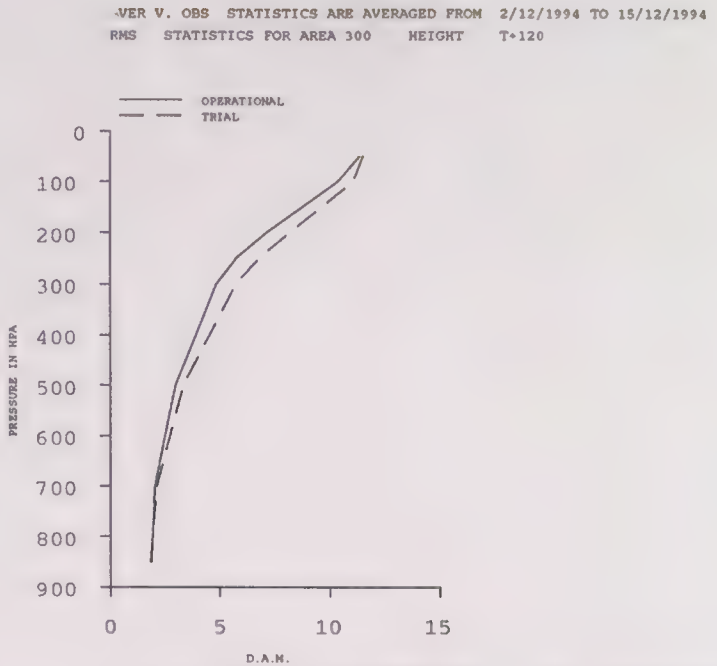
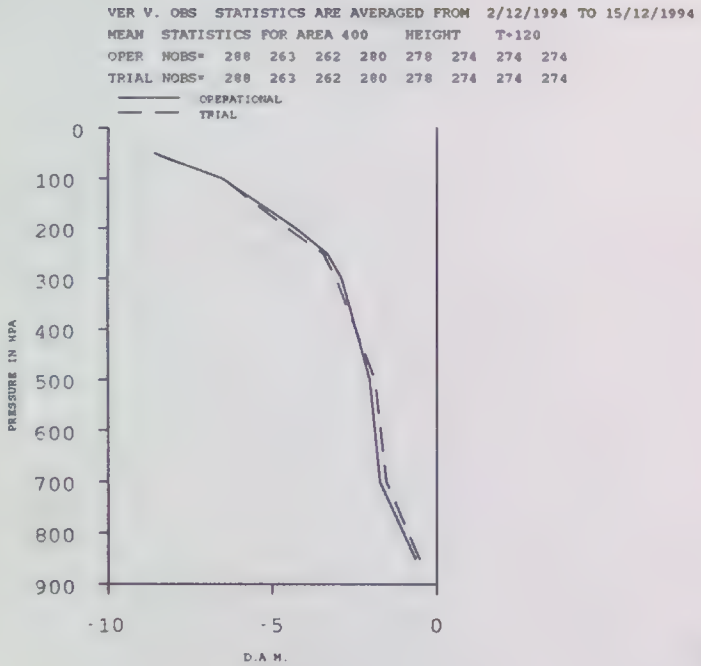

VER V. OBS STATISTICS ARE AVERAGED FROM 2/12/1994 TO 15/12/1994
RMS STATISTICS FOR AREA 400 HEIGHT T+72
OPERATIONAL
TRIAL
PRESSURE IN HPA
D.A.M.

FIGURE 4.6


VER V. OBS STATISTICS ARE AVERAGED FROM 2/12/1994 TO 15/12/1994
MEAN STATISTICS FOR AREA 300 HEIGHT T+120
OPER NOBS= 1612 1393 1394 1348 1314 1317 1240 817
TRIAL NOBS= 1612 1394 1394 1348 1315 1319 1239 818
OPERATIONAL
TRIAL
PRESSURE IN HPA
D.A.M.


VER V. OBS STATISTICS ARE AVERAGED FROM 2/12/1994 TO 15/12/1994
RMS STATISTICS FOR AREA 300 HEIGHT T+120
OPERATIONAL
TRIAL
PRESSURE IN HPA
D.A.M.


VER V. OBS STATISTICS ARE AVERAGED FROM 2/12/1994 TO 15/12/1994
MEAN STATISTICS FOR AREA 400 HEIGHT T+120
OPER NOBS= 288 263 262 280 278 274 274 274
TRIAL NOBS= 288 263 262 280 278 274 274 274
OPERATIONAL
TRIAL
PRESSURE IN HPA
D.A.M.

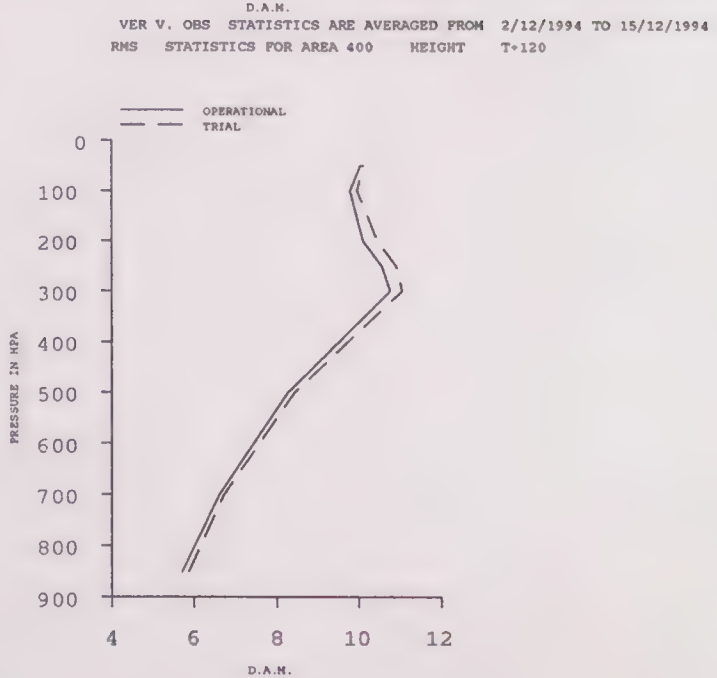
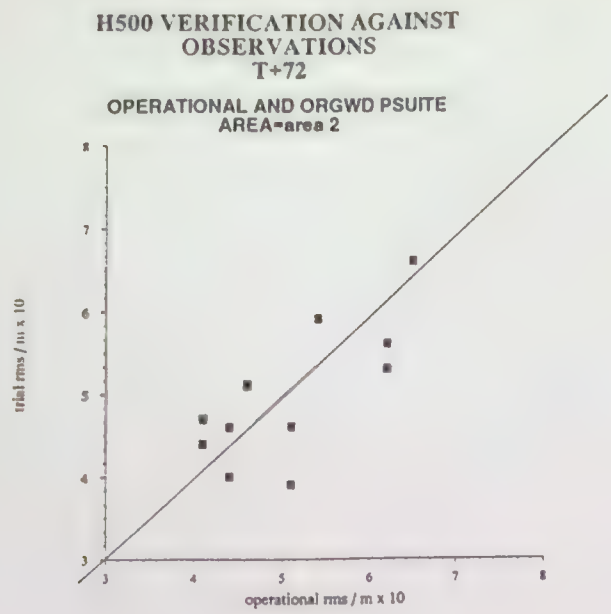
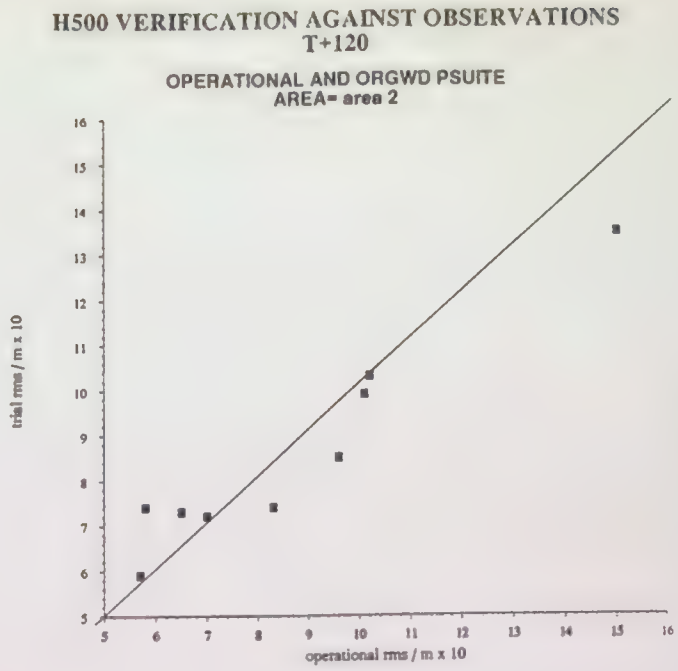
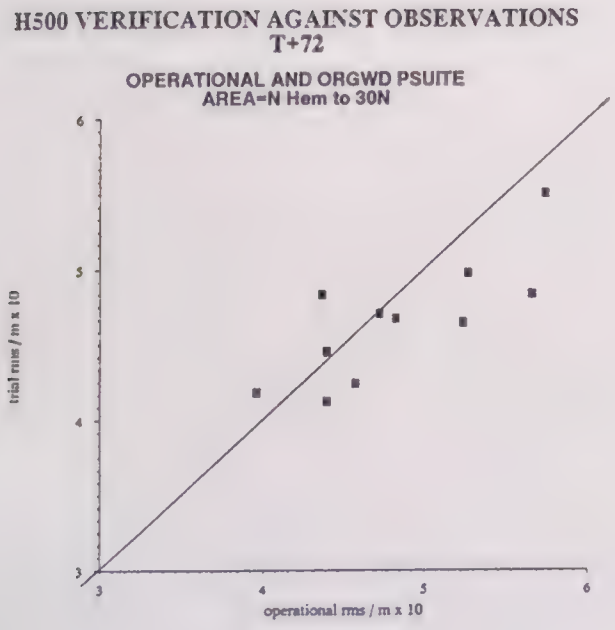

VER V. OBS STATISTICS ARE AVERAGED FROM 2/12/1994 TO 15/12/1994
RMS STATISTICS FOR AREA 400 HEIGHT T+120
OPERATIONAL
TRIAL
PRESSURE IN HPA
D.A.M.

FIGURE 4.7


H500 VERIFICATION AGAINST OBSERVATIONS
T+72
OPERATIONAL AND ORGWD PSUITE
AREA=area 2
trial rms / m x 10
operational rms / m x 10


H500 VERIFICATION AGAINST OBSERVATIONS
T+120
OPERATIONAL AND ORGWD PSUITE
AREA= area 2
trial rms / m x 10
operational rms / m x 10


H500 VERIFICATION AGAINST OBSERVATIONS
T+72
OPERATIONAL AND ORGWD PSUITE
AREA=N Hem to 30N
trial rms / m x 10
operational rms / m x 10

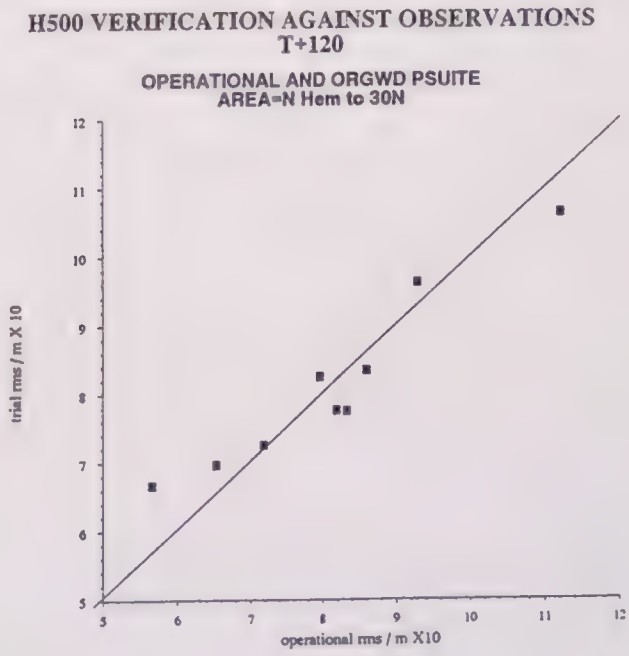
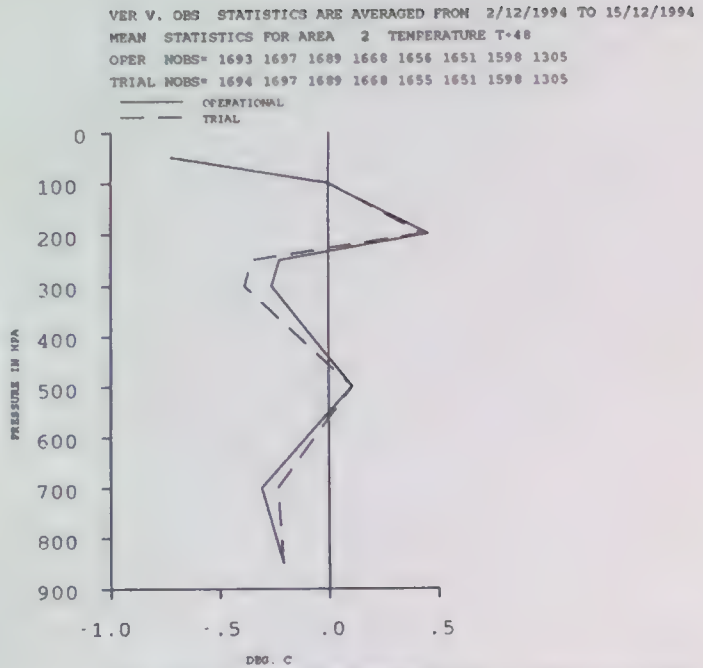
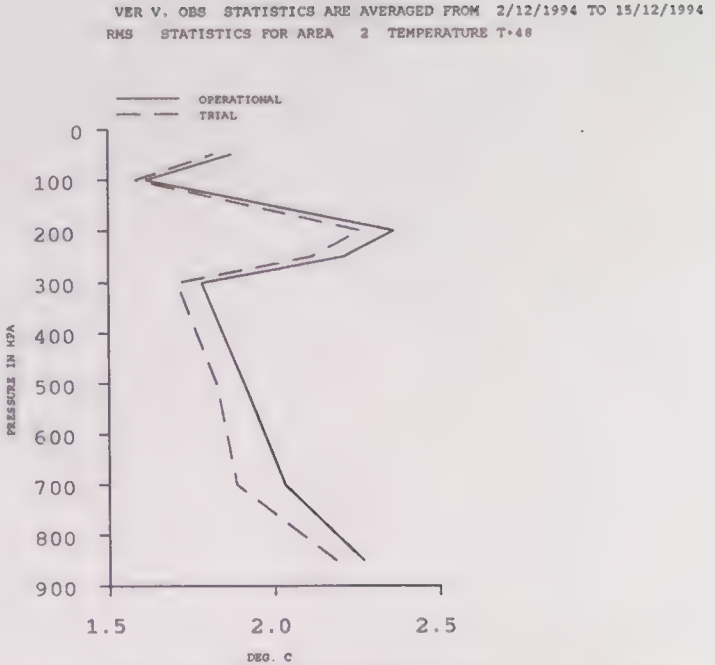
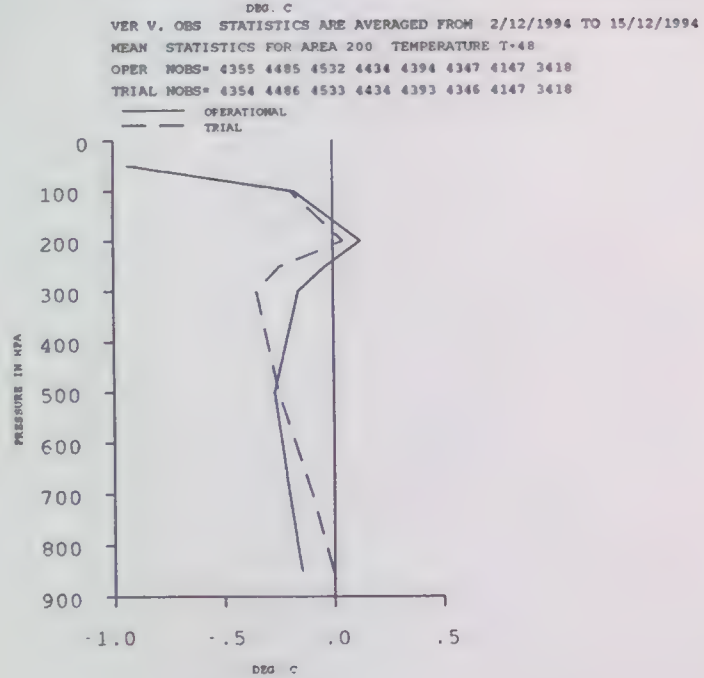

H500 VERIFICATION AGAINST OBSERVATIONS
T+120
OPERATIONAL AND ORGWD PSUITE
AREA=N Hem to 30N
trial rms / m X 10
operational rms / m X10

FIGURE 4.8


VER V. OBS STATISTICS ARE AVERAGED FROM 2/12/1994 TO 15/12/1994
MEAN STATISTICS FOR AREA 2 TEMPERATURE T+48
OPER NOBS= 1693 1697 1689 1668 1656 1651 1598 1305
TRIAL NOBS= 1694 1697 1689 1668 1655 1651 1598 1305
OPERATIONAL
TRIAL
PRESSURE IN HPA
0
100
200
300
400
500
600
700
800
900
-1.0
-.5
.0
.5
DEG. C


VER V. OBS STATISTICS ARE AVERAGED FROM 2/12/1994 TO 15/12/1994
RMS STATISTICS FOR AREA 2 TEMPERATURE T+48
OPERATIONAL
TRIAL
PRESSURE IN HPA
0
100
200
300
400
500
600
700
800
900
1.5
2.0
2.5
DEG. C


VER V. OBS STATISTICS ARE AVERAGED FROM 2/12/1994 TO 15/12/1994
MEAN STATISTICS FOR AREA 200 TEMPERATURE T+48
OPER NOBS= 4355 4485 4532 4434 4394 4347 4147 3418
TRIAL NOBS= 4354 4486 4533 4434 4393 4346 4147 3418
OPERATIONAL
TRIAL
PRESSURE IN HPA
0
100
200
300
400
500
600
700
800
900
-1.0
-.5
.0
.5
DEG C

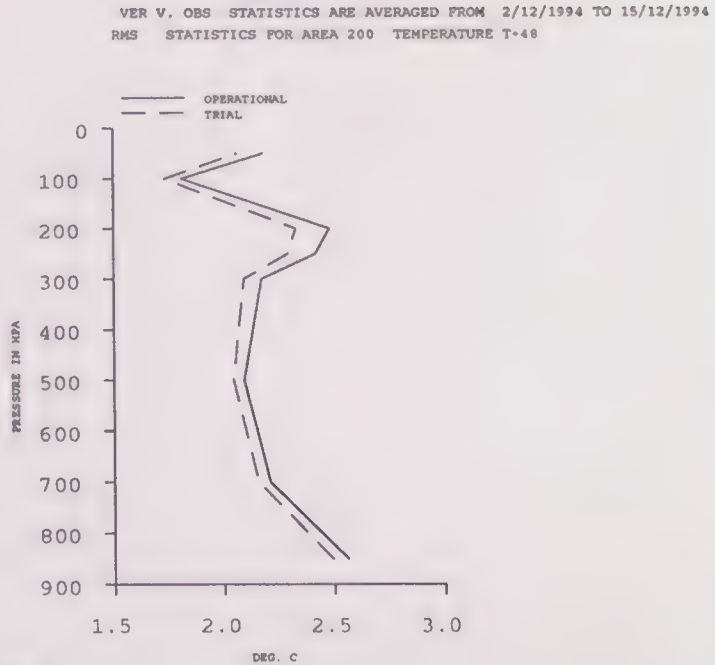

VER V. OBS STATISTICS ARE AVERAGED FROM 2/12/1994 TO 15/12/1994
RMS STATISTICS FOR AREA 200 TEMPERATURE T+48
OPERATIONAL
TRIAL
PRESSURE IN HPA
0
100
200
300
400
500
600
700
800
900
1.5
2.0
2.5
3.0
DEG. C

FIGURE 4.9

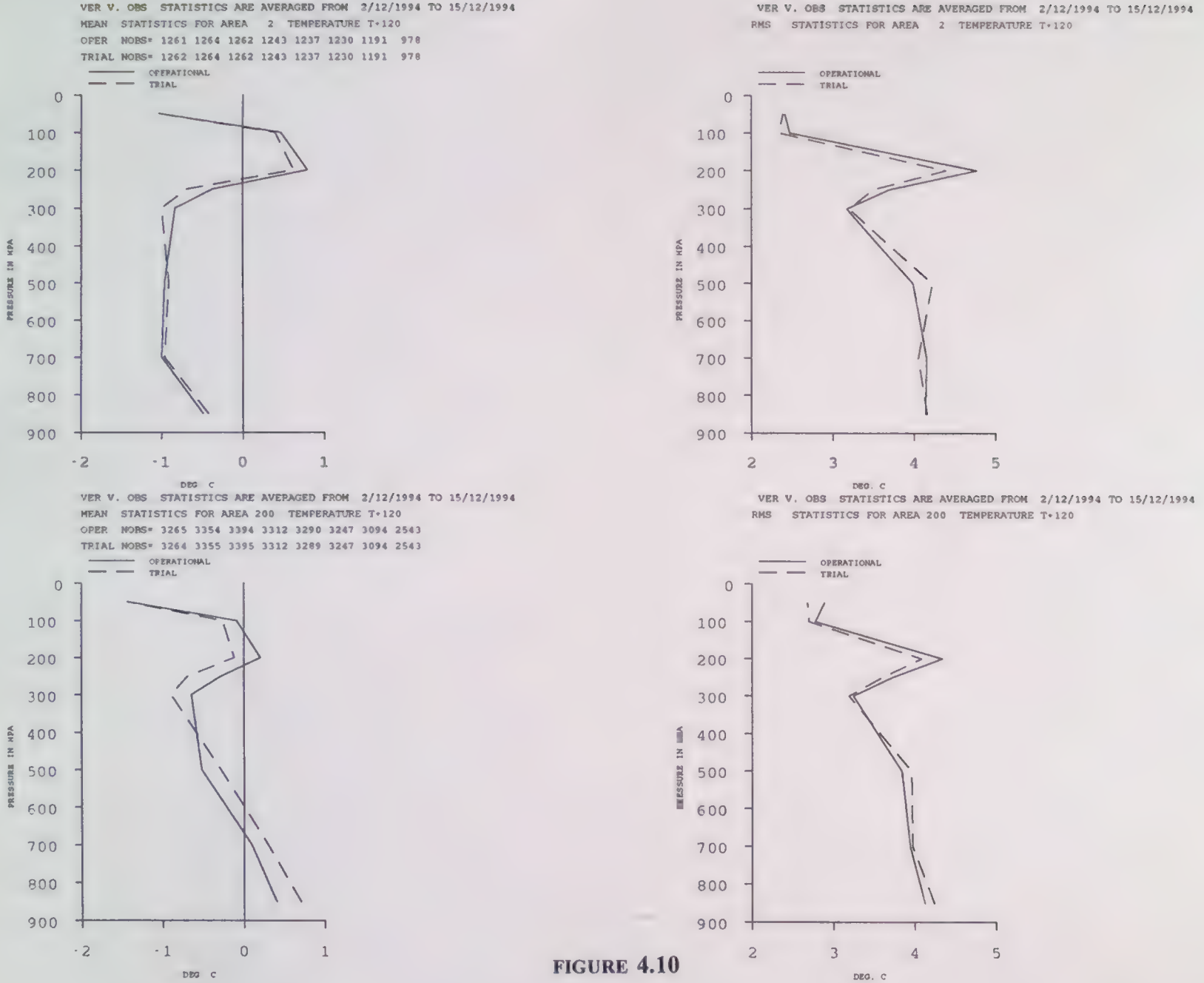
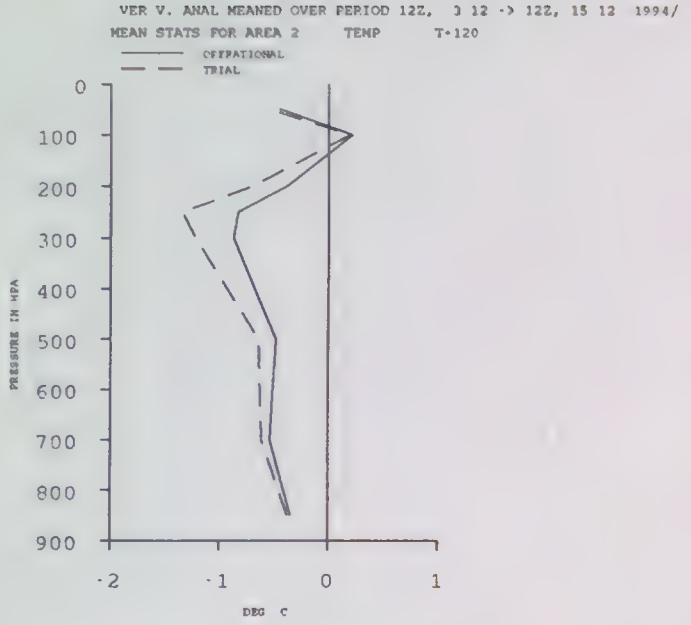
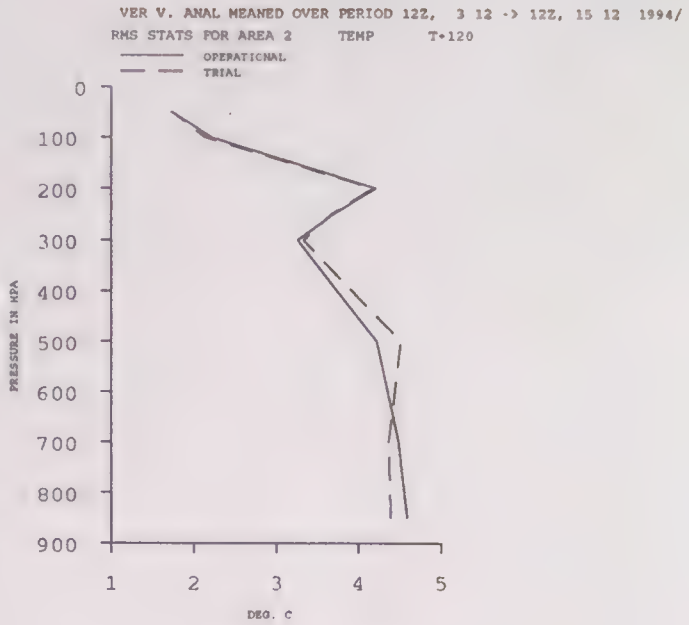
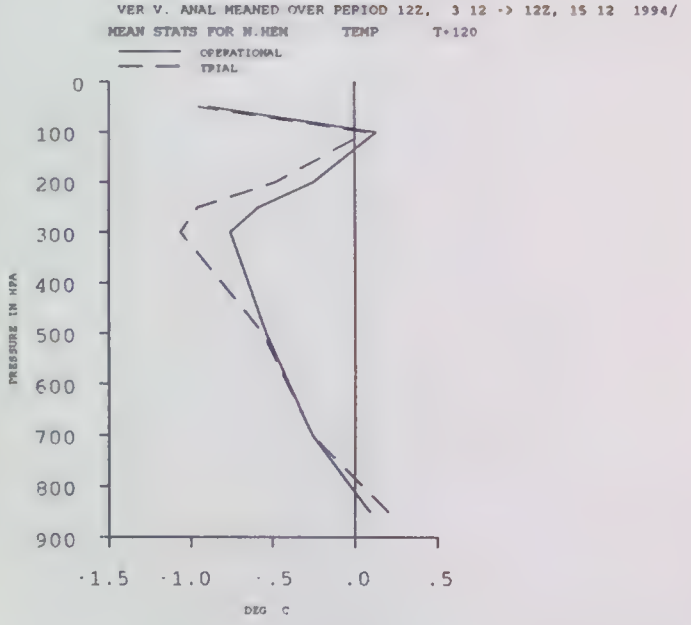

VER V. OBS STATISTICS ARE AVERAGED FROM 2/12/1994 TO 15/12/1994
MEAN STATISTICS FOR AREA 2 TEMPERATURE T+120
OPER NOBS= 1261 1264 1262 1243 1237 1230 1191 978
TRIAL NOBS= 1262 1264 1262 1243 1237 1230 1191 978
OPERATIONAL
TRIAL
PRESSURE IN HPA
DEG C
VER V. OBS STATISTICS ARE AVERAGED FROM 2/12/1994 TO 15/12/1994
RMS STATISTICS FOR AREA 2 TEMPERATURE T+120
OPERATIONAL
TRIAL
PRESSURE IN HPA
DEG. C
VER V. OBS STATISTICS ARE AVERAGED FROM 2/12/1994 TO 15/12/1994
MEAN STATISTICS FOR AREA 200 TEMPERATURE T+120
OPER NOBS= 3265 3354 3394 3312 3290 3247 3094 2543
TRIAL NOBS= 3264 3355 3395 3312 3289 3247 3094 2543
OPERATIONAL
TRIAL
PRESSURE IN HPA
DEG C
VER V. OBS STATISTICS ARE AVERAGED FROM 2/12/1994 TO 15/12/1994
RMS STATISTICS FOR AREA 200 TEMPERATURE T+120
OPERATIONAL
TRIAL
PRESSURE IN HPA
DEG. C

FIGURE 4.10


VER V. ANAL MEANED OVER PERIOD 12Z, 3 12 -> 12Z, 15 12 1994/
MEAN STATS FOR AREA 2 TEMP T+120
OPERATIONAL
TRIAL
PRESSURE IN HPA
0
100
200
300
400
500
600
700
800
900
-2
-1
0
1
DEG C


VER V. ANAL MEANED OVER PERIOD 12Z, 3 12 -> 12Z, 15 12 1994/
RMS STATS FOR AREA 2 TEMP T+120
OPERATIONAL
TRIAL
PRESSURE IN HPA
0
100
200
300
400
500
600
700
800
900
1
2
3
4
5
DEG. C


VER V. ANAL MEANED OVER PERIOD 12Z, 3 12 -> 12Z, 15 12 1994/
MEAN STATS FOR N.HEM TEMP T+120
OPERATIONAL
TRIAL
PRESSURE IN HPA
0
100
200
300
400
500
600
700
800
900
-1.5
-1.0
-.5
.0
.5
DEG C

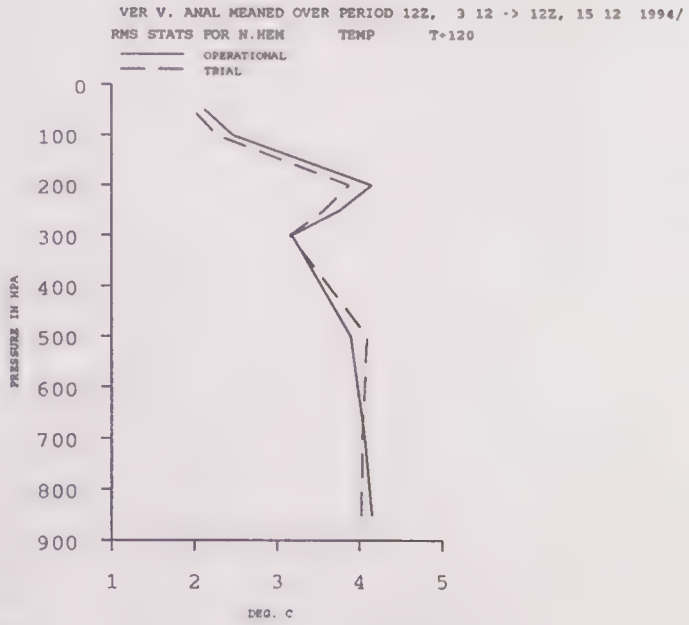

VER V. ANAL MEANED OVER PERIOD 12Z, 3 12 -> 12Z, 15 12 1994/
RMS STATS FOR N.HEM TEMP T+120
OPERATIONAL
TRIAL
PRESSURE IN HPA
0
100
200
300
400
500
600
700
800
900
1
2
3
4
5
DEG. C

FIGURE 4.11

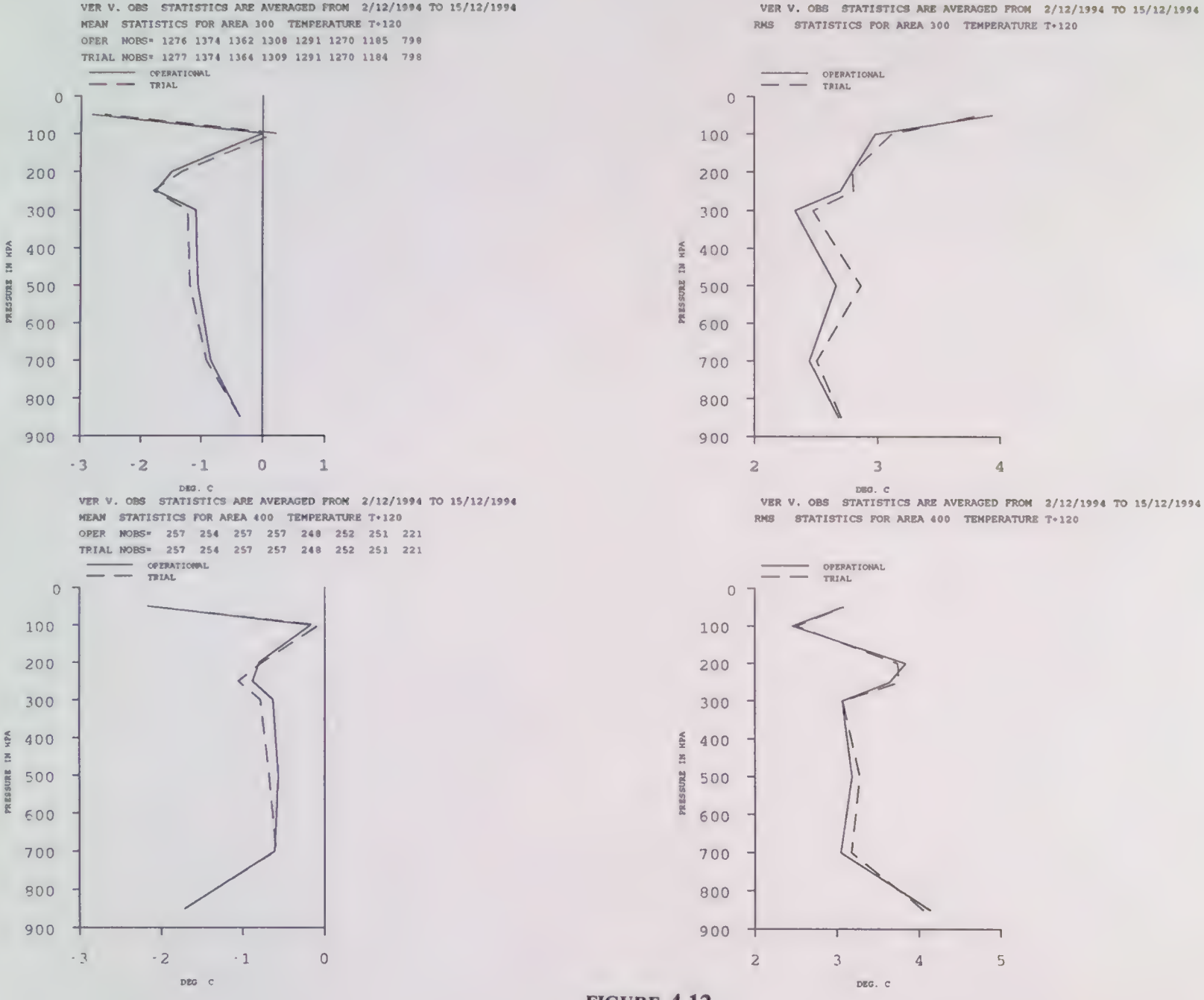

VER V. OBS STATISTICS ARE AVERAGED FROM 2/12/1994 TO 15/12/1994
MEAN STATISTICS FOR AREA 300 TEMPERATURE T+120
OPER NOBS= 1276 1374 1362 1308 1291 1270 1185 790
TRIAL NOBS= 1277 1374 1364 1309 1291 1270 1184 798
OPERATIONAL
TRIAL
PRESSURE IN HPA
DEG. C
VER V. OBS STATISTICS ARE AVERAGED FROM 2/12/1994 TO 15/12/1994
RMS STATISTICS FOR AREA 300 TEMPERATURE T+120
OPERATIONAL
TRIAL
PRESSURE IN HPA
DEG. C
VER V. OBS STATISTICS ARE AVERAGED FROM 2/12/1994 TO 15/12/1994
MEAN STATISTICS FOR AREA 400 TEMPERATURE T+120
OPER NOBS= 257 254 257 257 248 252 251 221
TRIAL NOBS= 257 254 257 257 248 252 251 221
OPERATIONAL
TRIAL
PRESSURE IN HPA
DEG C
VER V. OBS STATISTICS ARE AVERAGED FROM 2/12/1994 TO 15/12/1994
RMS STATISTICS FOR AREA 400 TEMPERATURE T+120
OPERATIONAL
TRIAL
PRESSURE IN HPA
DEG. C

FIGURE 4.12

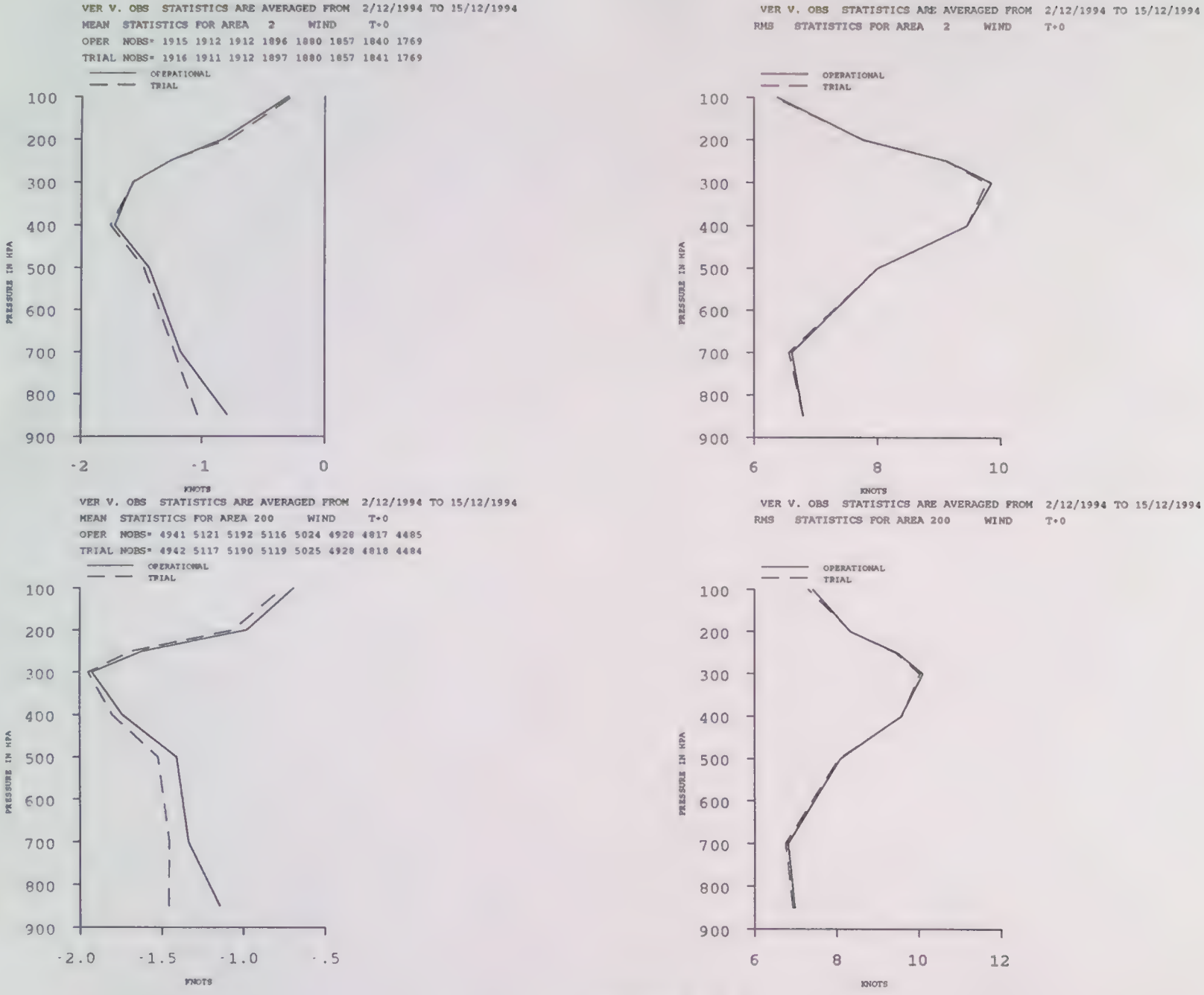

VER V. OBS STATISTICS ARE AVERAGED FROM 2/12/1994 TO 15/12/1994
MEAN STATISTICS FOR AREA 2 WIND T+0
OPER NOBS= 1915 1912 1912 1896 1880 1857 1840 1769
TRIAL NOBS= 1916 1911 1912 1897 1880 1857 1841 1769
OPERATIONAL
TRIAL
PRESSURE IN HPA
100
200
300
400
500
600
700
800
900
-2
-1
0
KNOTS
VER V. OBS STATISTICS ARE AVERAGED FROM 2/12/1994 TO 15/12/1994
RMS STATISTICS FOR AREA 2 WIND T+0
OPERATIONAL
TRIAL
PRESSURE IN HPA
6
8
10
KNOTS
VER V. OBS STATISTICS ARE AVERAGED FROM 2/12/1994 TO 15/12/1994
MEAN STATISTICS FOR AREA 200 WIND T+0
OPER NOBS= 4941 5121 5192 5116 5024 4920 4817 4485
TRIAL NOBS= 4942 5117 5190 5119 5025 4920 4818 4484
OPERATIONAL
TRIAL
PRESSURE IN HPA
-2.0
-1.5
-1.0
-.5
KNOTS
VER V. OBS STATISTICS ARE AVERAGED FROM 2/12/1994 TO 15/12/1994
RMS STATISTICS FOR AREA 200 WIND T+0
OPERATIONAL
TRIAL
PRESSURE IN HPA
6
8
10
12
KNOTS

FIGURE 4.13

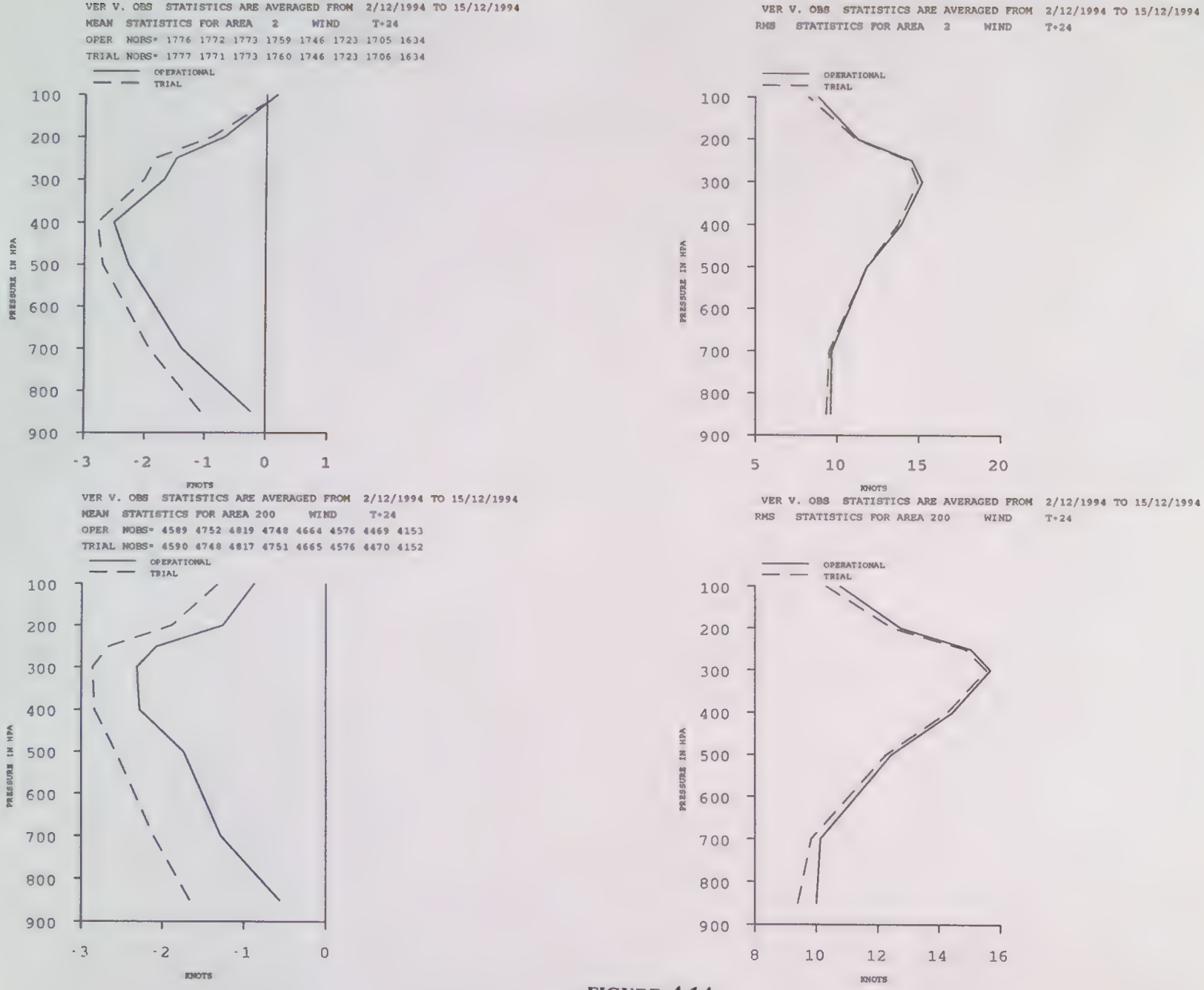

VER V. OBS STATISTICS ARE AVERAGED FROM 2/12/1994 TO 15/12/1994
MEAN STATISTICS FOR AREA 2 WIND T+24
OPER NOBS= 1776 1772 1773 1759 1746 1723 1705 1634
TRIAL NOBS= 1777 1771 1773 1760 1746 1723 1706 1634
OPERATIONAL
TRIAL
PRESSURE IN HPA
100
200
300
400
500
600
700
800
900
-3
-2
-1
0
1
KNOTS
VER V. OBS STATISTICS ARE AVERAGED FROM 2/12/1994 TO 15/12/1994
RMS STATISTICS FOR AREA 2 WIND T+24
OPERATIONAL
TRIAL
PRESSURE IN HPA
100
200
300
400
500
600
700
800
900
5
10
15
20
KNOTS
VER V. OBS STATISTICS ARE AVERAGED FROM 2/12/1994 TO 15/12/1994
MEAN STATISTICS FOR AREA 200 WIND T+24
OPER NOBS= 4589 4752 4819 4748 4664 4576 4469 4153
TRIAL NOBS= 4590 4748 4817 4751 4665 4576 4470 4152
OPERATIONAL
TRIAL
PRESSURE IN HPA
100
200
300
400
500
600
700
800
900
-3
-2
-1
0
KNOTS
VER V. OBS STATISTICS ARE AVERAGED FROM 2/12/1994 TO 15/12/1994
RMS STATISTICS FOR AREA 200 WIND T+24
OPERATIONAL
TRIAL
PRESSURE IN HPA
100
200
300
400
500
600
700
800
900
8
10
12
14
16
KNOTS

FIGURE 4.14

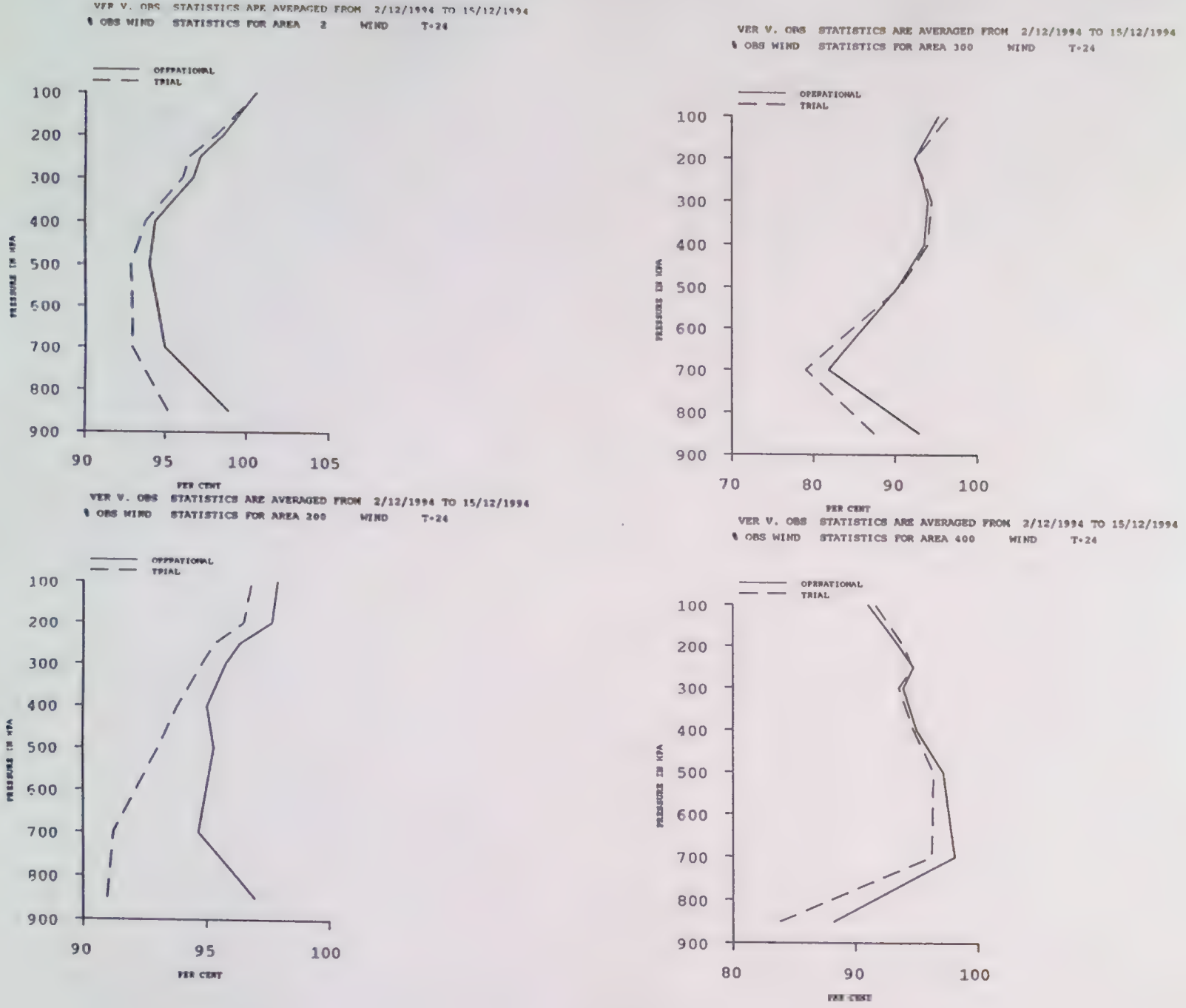

VER V. OBS STATISTICS ARE AVERAGED FROM 2/12/1994 TO 15/12/1994
% OBS WIND STATISTICS FOR AREA 2 WIND T+24
OPERATIONAL
TRIAL
100
200
300
400
500
600
700
800
900
90
95
100
105
PER CENT
VER V. OBS STATISTICS ARE AVERAGED FROM 2/12/1994 TO 15/12/1994
% OBS WIND STATISTICS FOR AREA 300 WIND T+24
OPERATIONAL
TRIAL
70
80
90
100
PER CENT
VER V. OBS STATISTICS ARE AVERAGED FROM 2/12/1994 TO 15/12/1994
% OBS WIND STATISTICS FOR AREA 200 WIND T+24
OPERATIONAL
TRIAL
PER CENT
VER V. OBS STATISTICS ARE AVERAGED FROM 2/12/1994 TO 15/12/1994
% OBS WIND STATISTICS FOR AREA 400 WIND T+24
OPERATIONAL
TRIAL
80
90
100

FIGURE 4.15

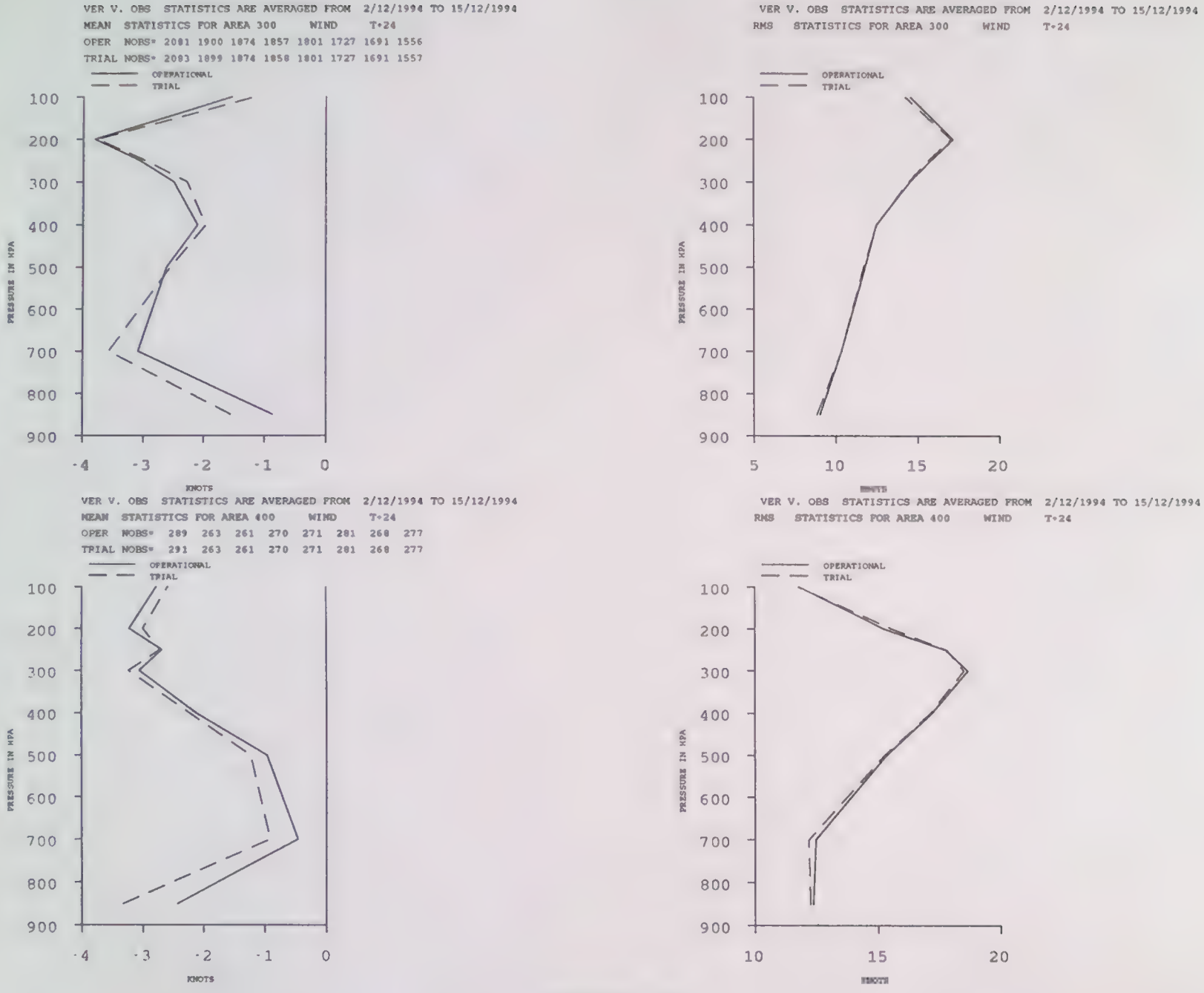
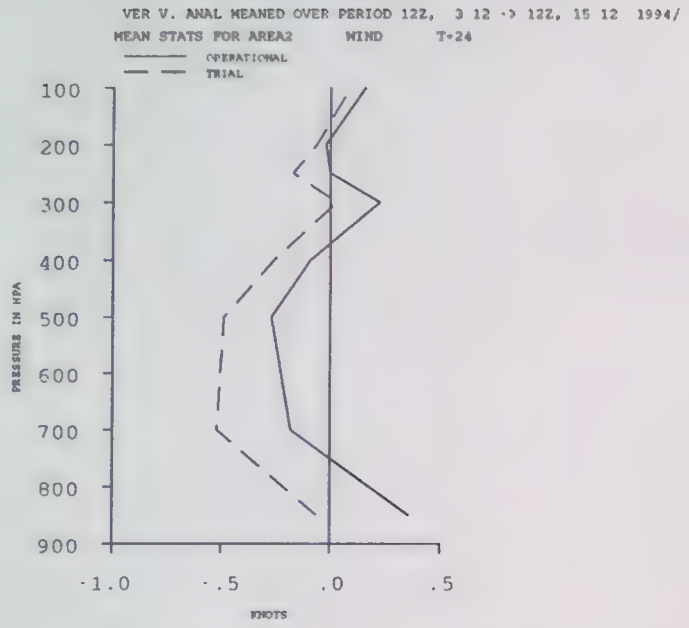
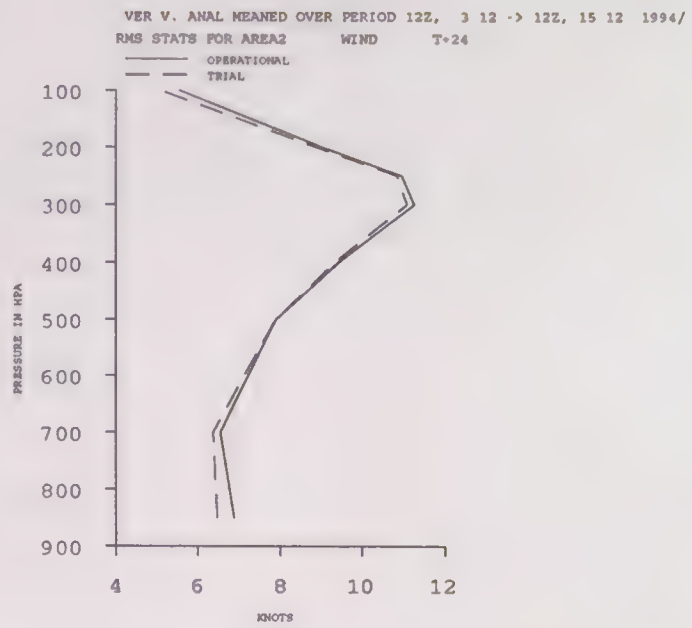
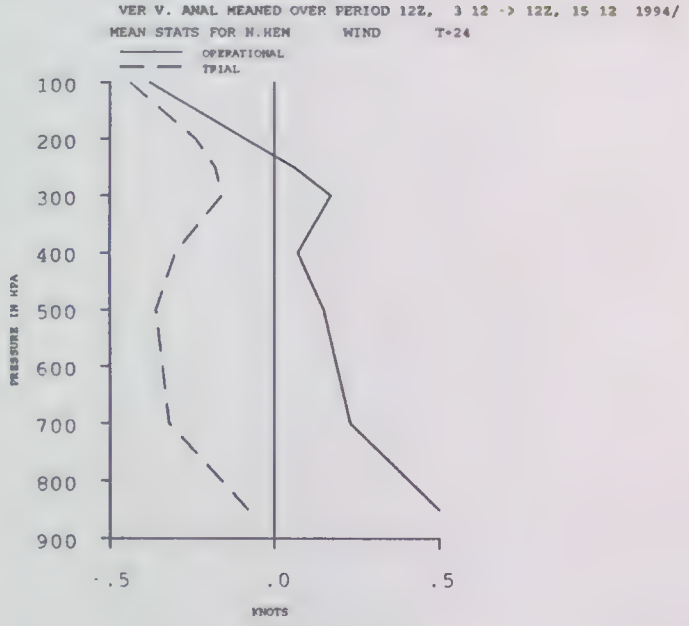

VER V. OBS STATISTICS ARE AVERAGED FROM 2/12/1994 TO 15/12/1994
MEAN STATISTICS FOR AREA 300 WIND T+24
OPER NOBS= 2081 1900 1874 1857 1801 1727 1691 1556
TRIAL NOBS= 2083 1899 1874 1858 1801 1727 1691 1557
OPERATIONAL
TRIAL
PRESSURE IN HPA
100
200
300
400
500
600
700
800
900
-4
-3
-2
-1
0
KNOTS
VER V. OBS STATISTICS ARE AVERAGED FROM 2/12/1994 TO 15/12/1994
RMS STATISTICS FOR AREA 300 WIND T+24
OPERATIONAL
TRIAL
PRESSURE IN HPA
100
200
300
400
500
600
700
800
900
5
10
15
20
KNOTS
VER V. OBS STATISTICS ARE AVERAGED FROM 2/12/1994 TO 15/12/1994
MEAN STATISTICS FOR AREA 400 WIND T+24
OPER NOBS= 289 263 261 270 271 281 268 277
TRIAL NOBS= 291 263 261 270 271 281 268 277
OPERATIONAL
TRIAL
PRESSURE IN HPA
100
200
300
400
500
600
700
800
900
-4
-3
-2
-1
0
KNOTS
VER V. OBS STATISTICS ARE AVERAGED FROM 2/12/1994 TO 15/12/1994
RMS STATISTICS FOR AREA 400 WIND T+24
OPERATIONAL
TRIAL
PRESSURE IN HPA
100
200
300
400
500
600
700
800
900
10
15
20
KNOTS

FIGURE 4.16


VER V. ANAL MEANED OVER PERIOD 12Z, 3 12 -> 12Z, 15 12 1994/
MEAN STATS FOR AREA2 WIND T+24
OPERATIONAL
TRIAL
100
200
300
400
500
600
700
800
900
PRESSURE IN HPA
-1.0
-.5
.0
.5
KNOTS


VER V. ANAL MEANED OVER PERIOD 12Z, 3 12 -> 12Z, 15 12 1994/
RMS STATS FOR AREA2 WIND T+24
OPERATIONAL
TRIAL
100
200
300
400
500
600
700
800
900
PRESSURE IN HPA
4
6
8
10
12
KNOTS


VER V. ANAL MEANED OVER PERIOD 12Z, 3 12 -> 12Z, 15 12 1994/
MEAN STATS FOR N.HEM WIND T+24
OPERATIONAL
TRIAL
100
200
300
400
500
600
700
800
900
PRESSURE IN HPA
-.5
.0
.5
KNOTS

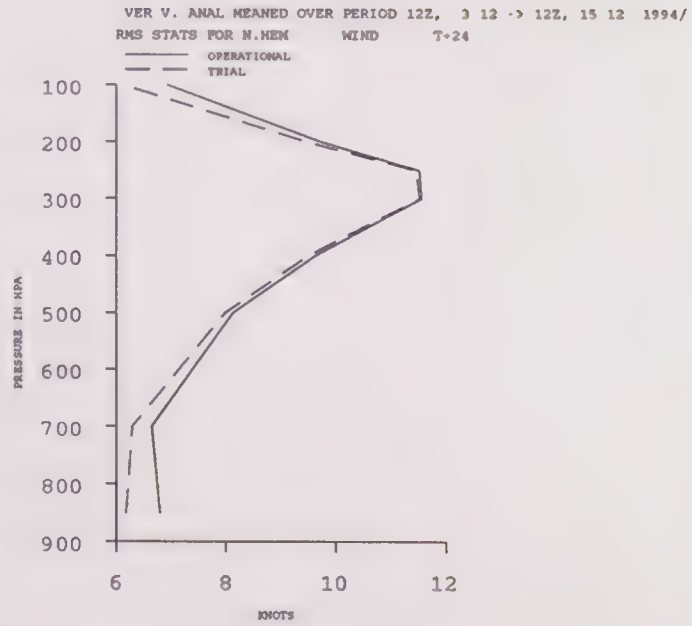

VER V. ANAL MEANED OVER PERIOD 12Z, 3 12 -> 12Z, 15 12 1994/
RMS STATS FOR N.HEM WIND T+24
OPERATIONAL
TRIAL
100
200
300
400
500
600
700
800
900
PRESSURE IN HPA
6
8
10
12
KNOTS

FIGURE 4.17

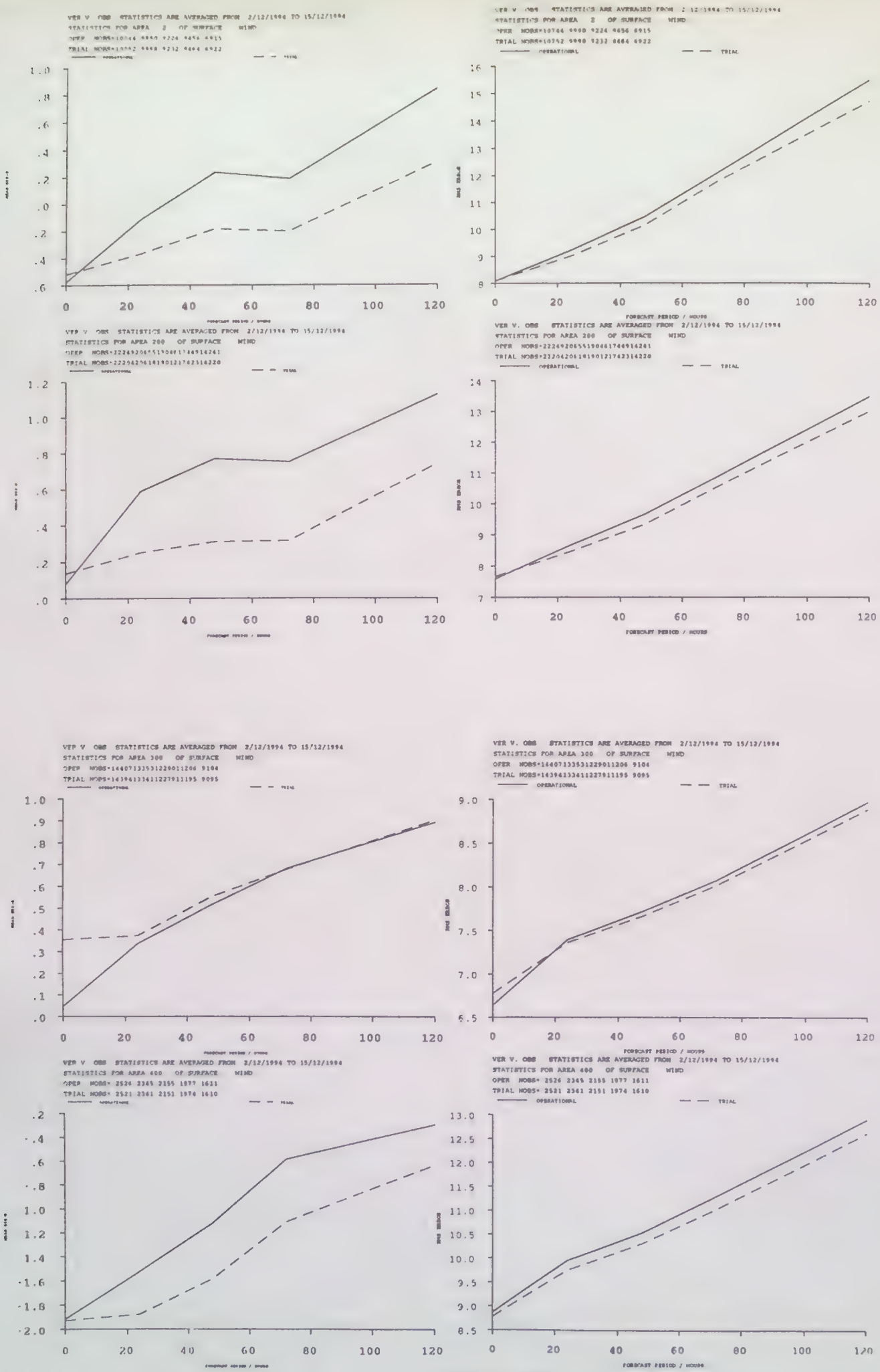

VER V OBS STATISTICS ARE AVERAGED FROM 2/12/1994 TO 15/12/1994
STATISTICS FOR AREA 2 OF SURFACE WIND
OPER NOBS=10744 9990 9224 9456 6915
TRIAL NOBS=10752 9990 9232 9464 6922
OPERATIONAL
TRIAL
FORECAST PERIOD / HOURS
VER V OBS STATISTICS ARE AVERAGED FROM 2/12/1994 TO 15/12/1994
STATISTICS FOR AREA 200 OF SURFACE WIND
OPER NOBS=22249206551904617449142 41
TRIAL NOBS=22204206191901217423142 20
OPERATIONAL
TRIAL
FORECAST PERIOD / HOURS
VER V OBS STATISTICS ARE AVERAGED FROM 2/12/1994 TO 15/12/1994
STATISTICS FOR AREA 300 OF SURFACE WIND
OPER NOBS=14407133531229011206 9104
TRIAL NOBS=14394133411227911195 9095
OPERATIONAL
TRIAL
FORECAST PERIOD / HOURS
VER V OBS STATISTICS ARE AVERAGED FROM 2/12/1994 TO 15/12/1994
STATISTICS FOR AREA 400 OF SURFACE WIND
OPER NOBS= 2526 2345 2155 1977 1611
TRIAL NOBS= 2521 2341 2151 1974 1610
OPERATIONAL
TRIAL
FORECAST PERIOD / HOURS

FIGURE 4.18

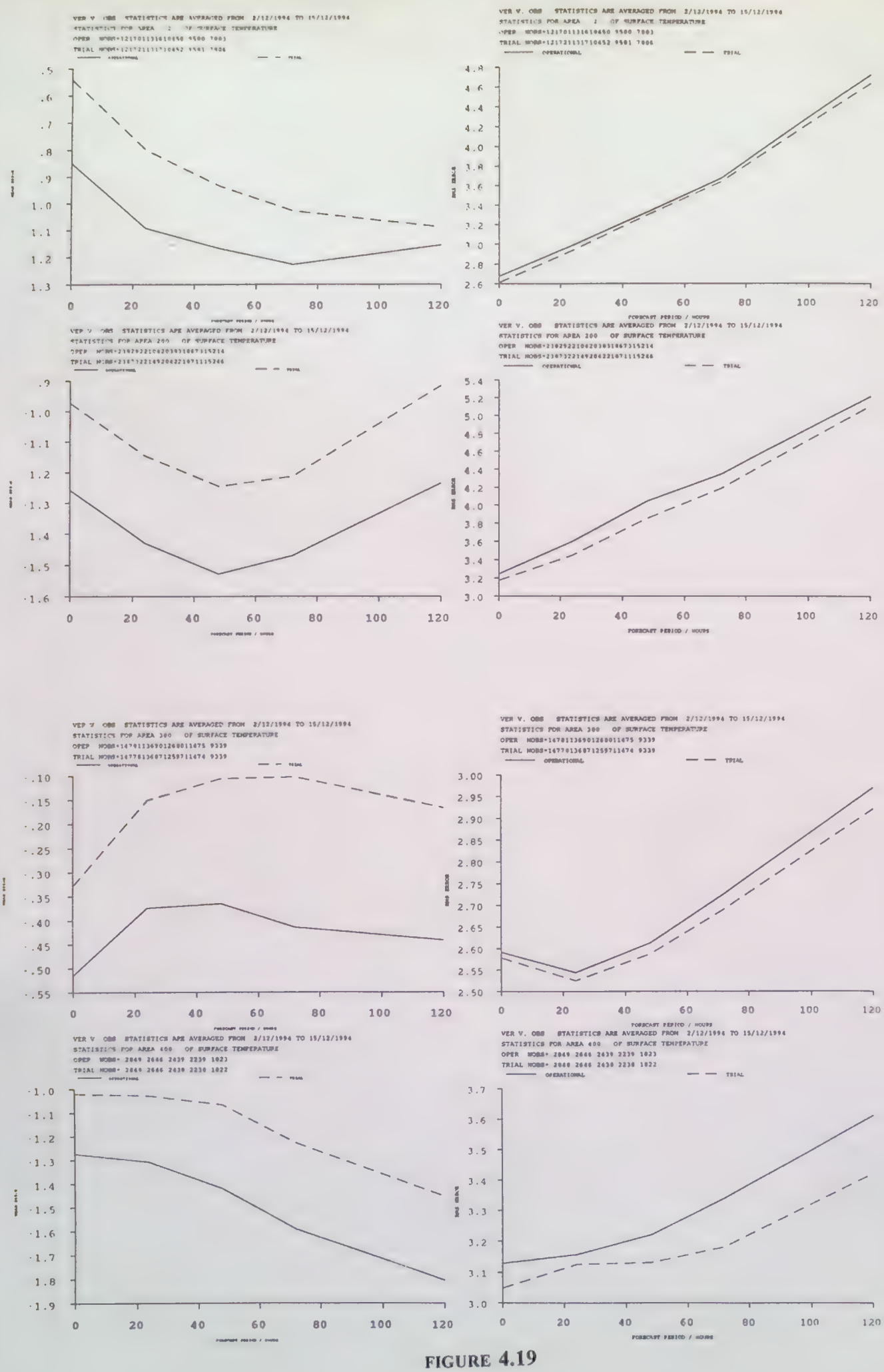
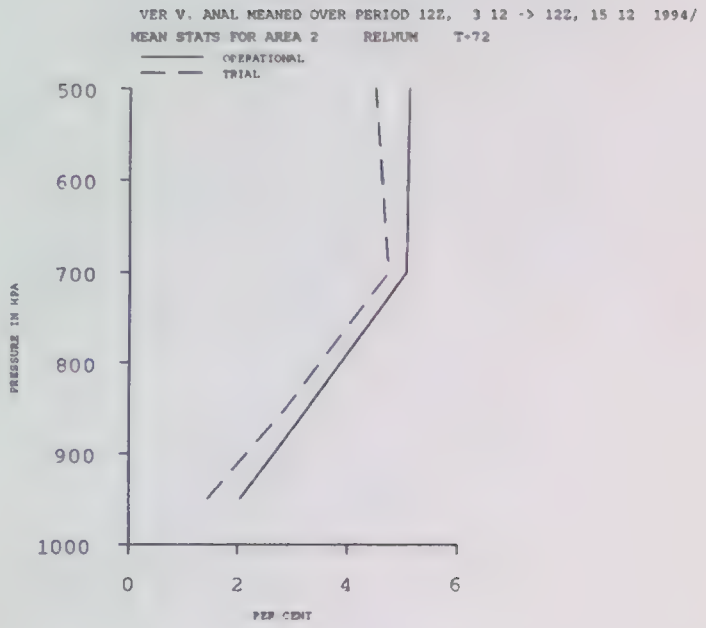
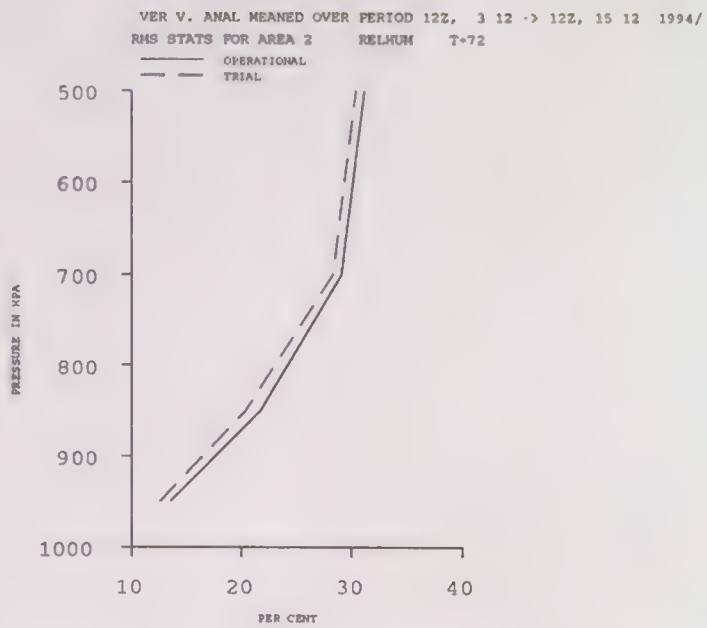
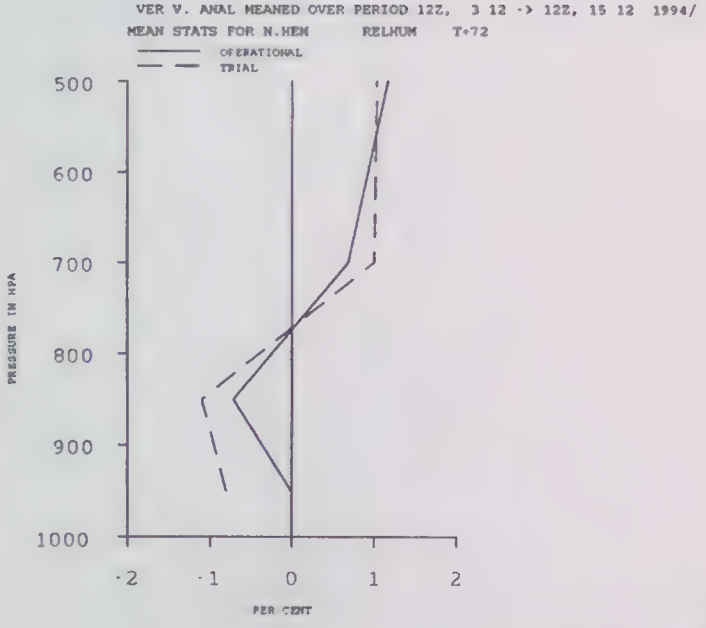


FIGURE 4.19


VER V. ANAL MEANED OVER PERIOD 12Z, 3 12 -> 12Z, 15 12 1994/
MEAN STATS FOR AREA 2 RELHUM T+72
OPERATIONAL
TRIAL
PRESSURE IN HPA
500
600
700
800
900
1000
0
2
4
6
PER CENT


VER V. ANAL MEANED OVER PERIOD 12Z, 3 12 -> 12Z, 15 12 1994/
RMS STATS FOR AREA 2 RELHUM T+72
OPERATIONAL
TRIAL
PRESSURE IN HPA
500
600
700
800
900
1000
10
20
30
40
PER CENT


VER V. ANAL MEANED OVER PERIOD 12Z, 3 12 -> 12Z, 15 12 1994/
MEAN STATS FOR N.HEM RELHUM T+72
OPERATIONAL
TRIAL
PRESSURE IN HPA
500
600
700
800
900
1000
-2
-1
0
1
2
PER CENT

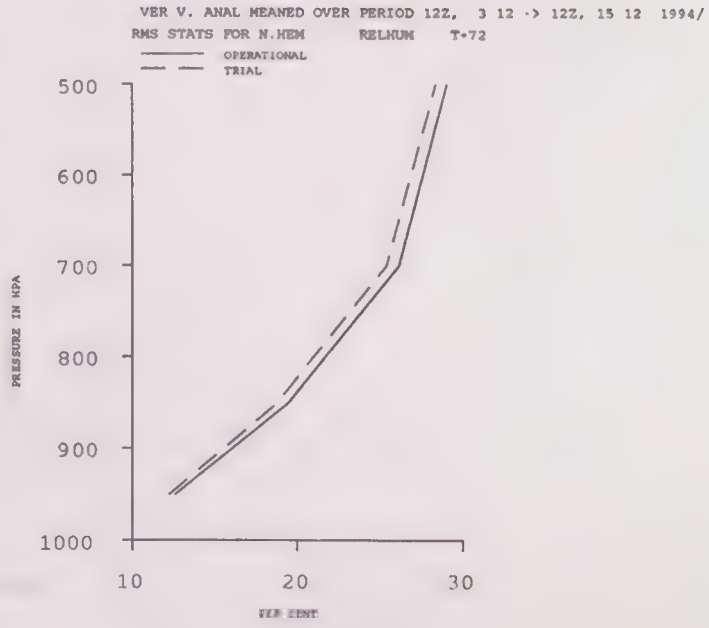

VER V. ANAL MEANED OVER PERIOD 12Z, 3 12 -> 12Z, 15 12 1994/
RMS STATS FOR N.HEM RELHUM T+72
OPERATIONAL
TRIAL
PRESSURE IN HPA
500
600
700
800
900
1000
10
20
30
PER CENT

FIGURE 4.20

MEAN SEA LEVEL PRESSURE DIFFERENCES IN NORTHERN HEMISPHERE
TRIAL 2(NEW GRAVITY WAVE / OROGRAPHIC ROUGHNESS) - OPERATIONAL
MEANED OVER PERIOD 12Z 03/12/94 - 12Z 16/12/94
T+24 F/C (negative differences shaded,contours 1.0 hPa)

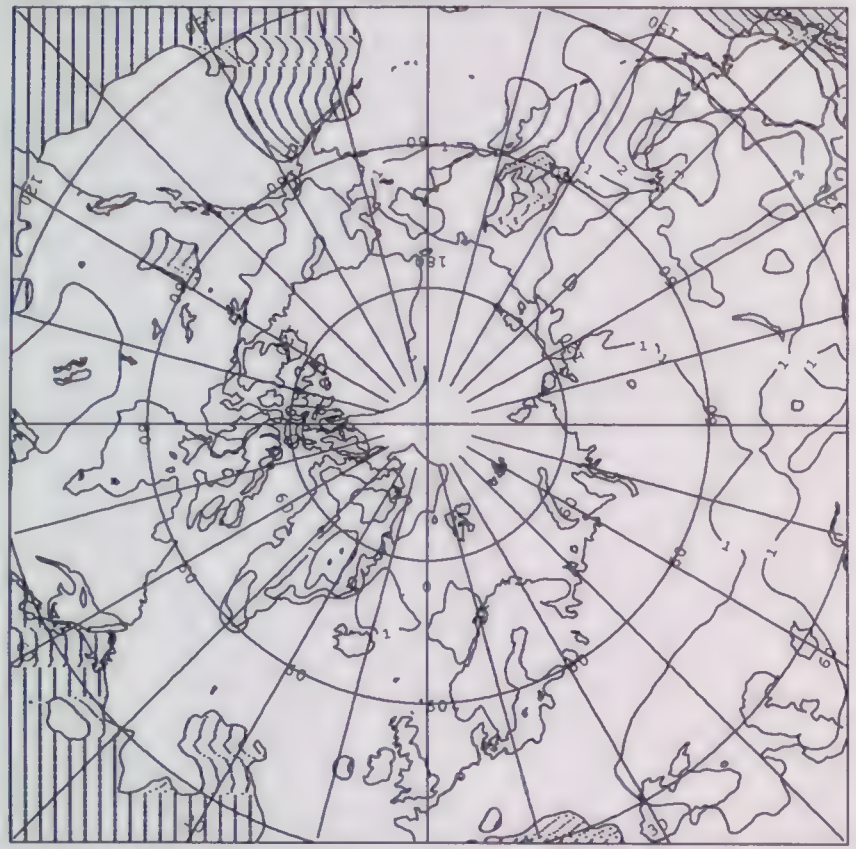


FIGURE 5.1(a)

MEAN SEA LEVEL PRESSURE DIFFERENCES IN SOUTHERN HEMISPHERE
TRIAL 2(NEW GRAVITY WAVE / OROGRAPHIC ROUGHNESS) - OPERATIONAL
MEANED OVER PERIOD 12Z 03/12/94 - 12Z 16/12/94
T+24 F/C (negative differences shaded,contours 1.0 hPa)

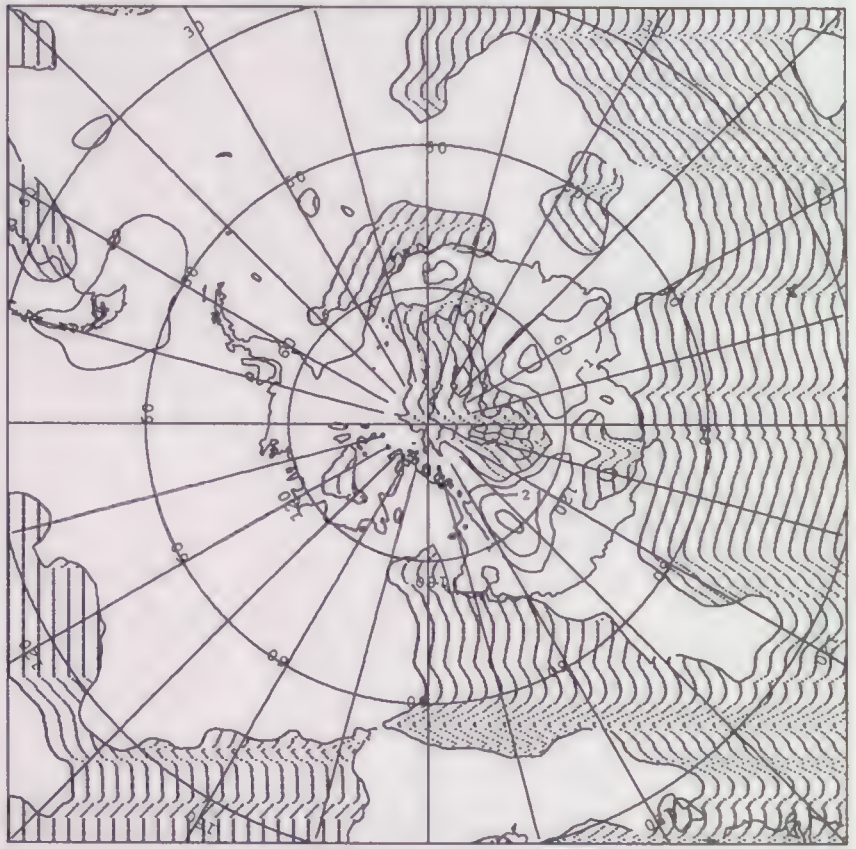
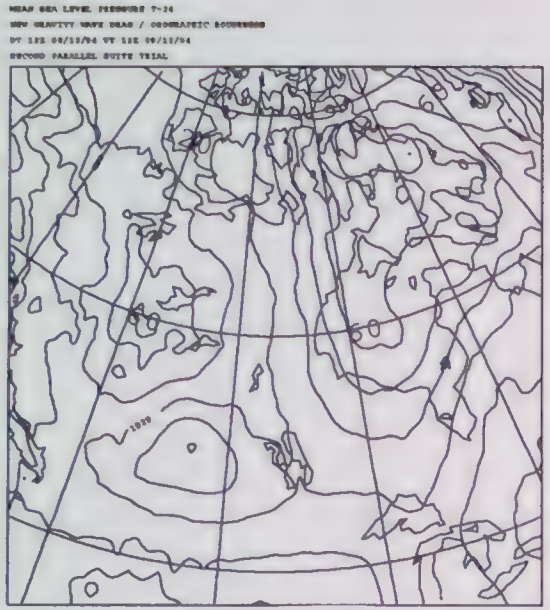
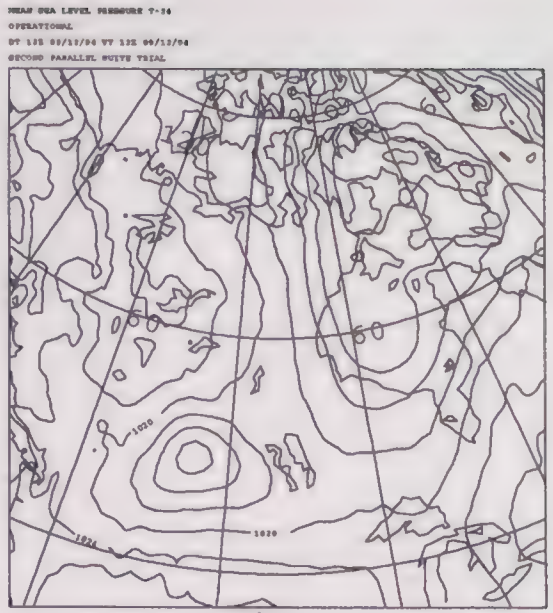


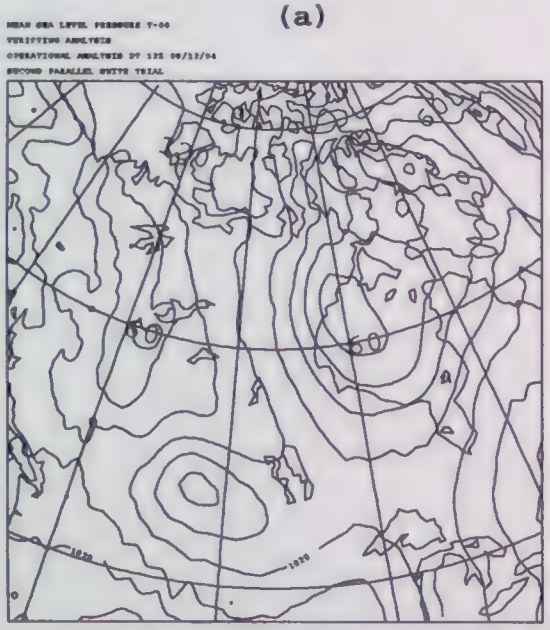
FIGURE 5.1(b)



(a)



(b)



(c)

FIGURE 5.2
T+24 FORECAST VT 12Z 09/12/94
(a) TRIAL (NEW GRAVITY WAVE DRAG/OROGRAPHIC ROUGHNESS)
(b) OPERATIONAL

(c) OPERATIONAL ANALYSIS

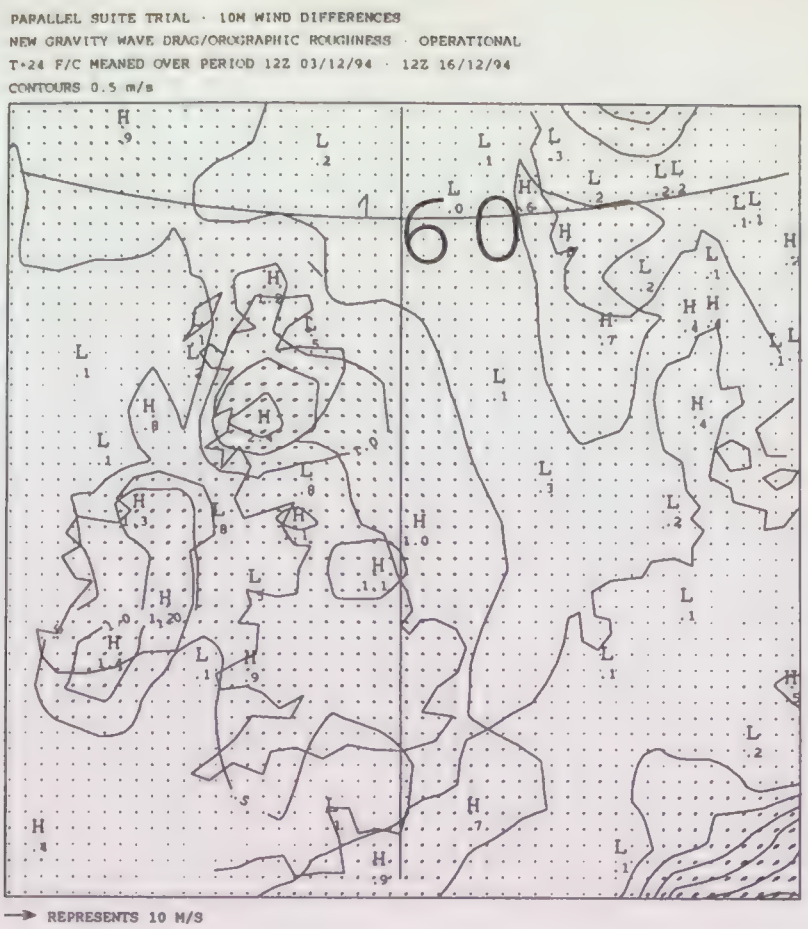


FIGURE 5.3 (a) 10M WIND DIFFERENCES T+24 (TRIAL - OPERATIONAL)

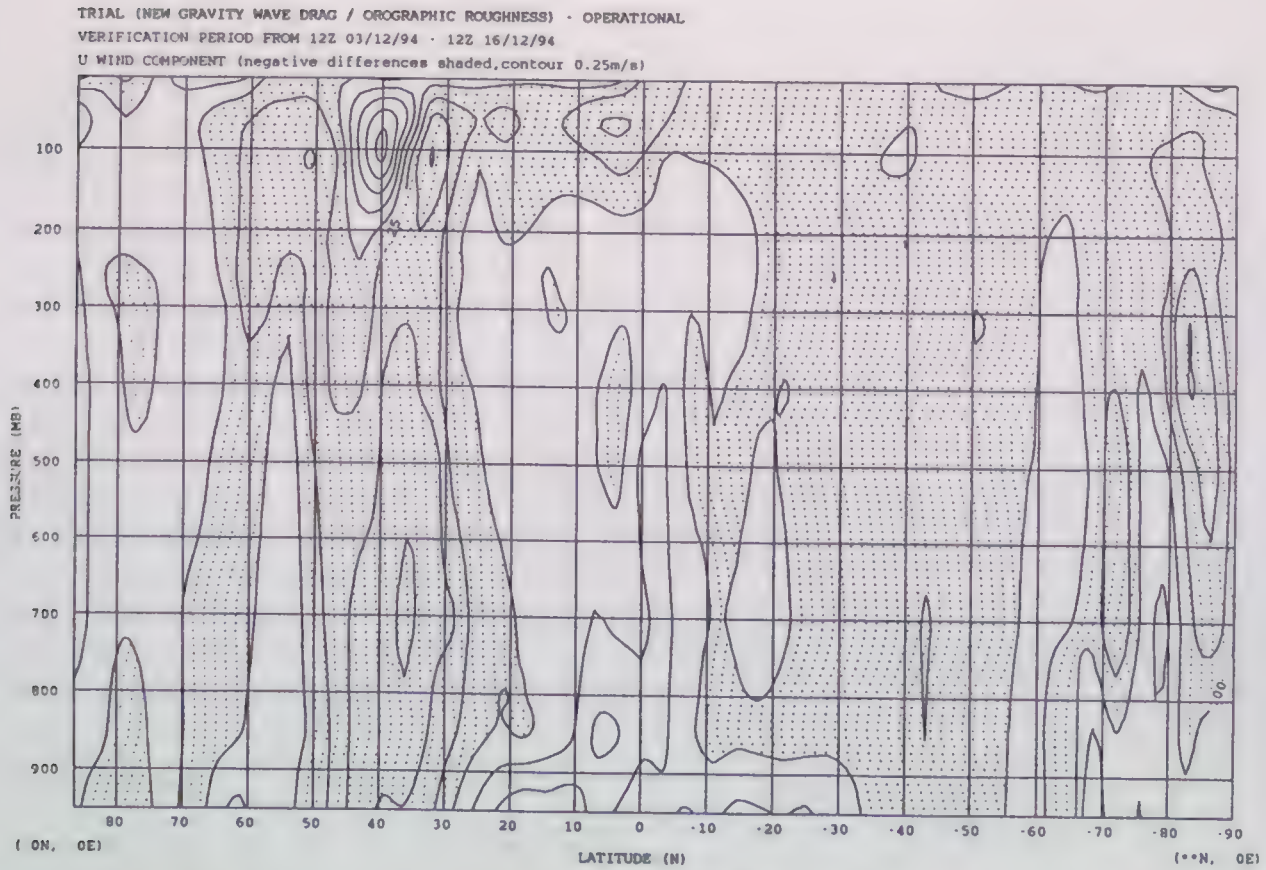
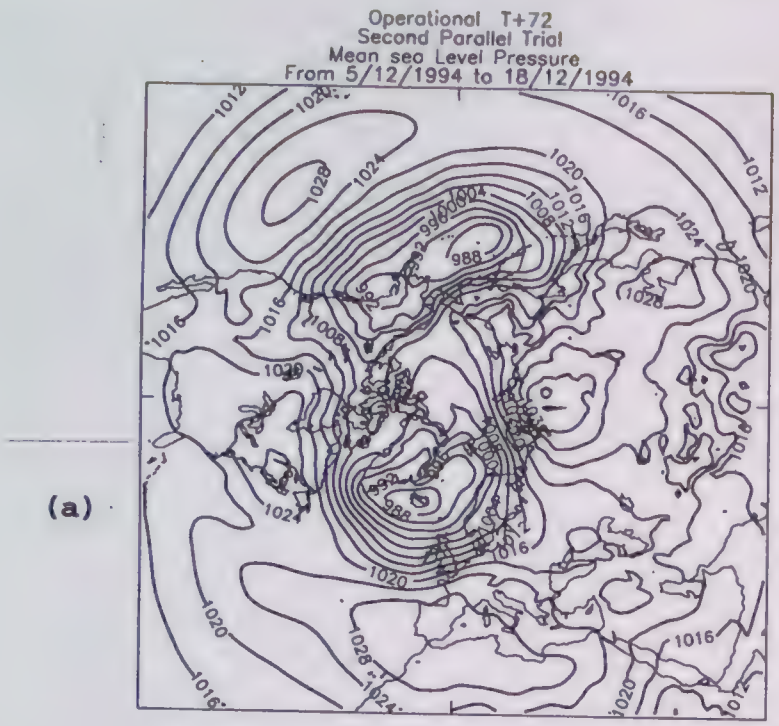
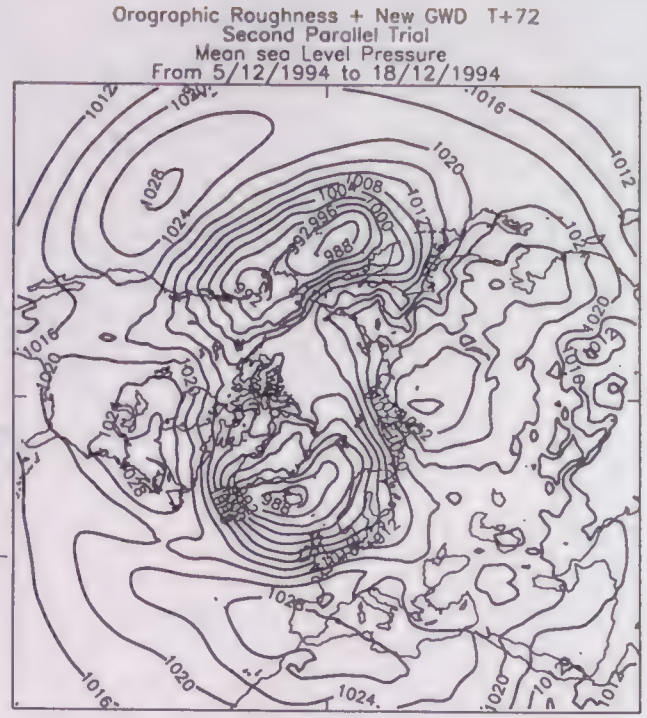


FIGURE 5.3(b) ZONAL MEAN CROSS-SECTION T+24 F/C WESTERLY WIND COMPONENT DIFFERENCES (TRIAL-OPERATIONAL)



(a)



(b)

(c)

FIGURE 5.4
MEAN SEA LEVEL PRESSURE FORECAST T+72
(MEANED OVER PERIOD 12z 5/12/94 TO 12z 18/12/94)
(a) OPERATIONAL
(b) TRIAL (NEW GRAVITY WAVE DRAG/OROGRAPHIC ROUGHNESS
(c) DIFFERENCES (TRIAL - OPERATIONAL)

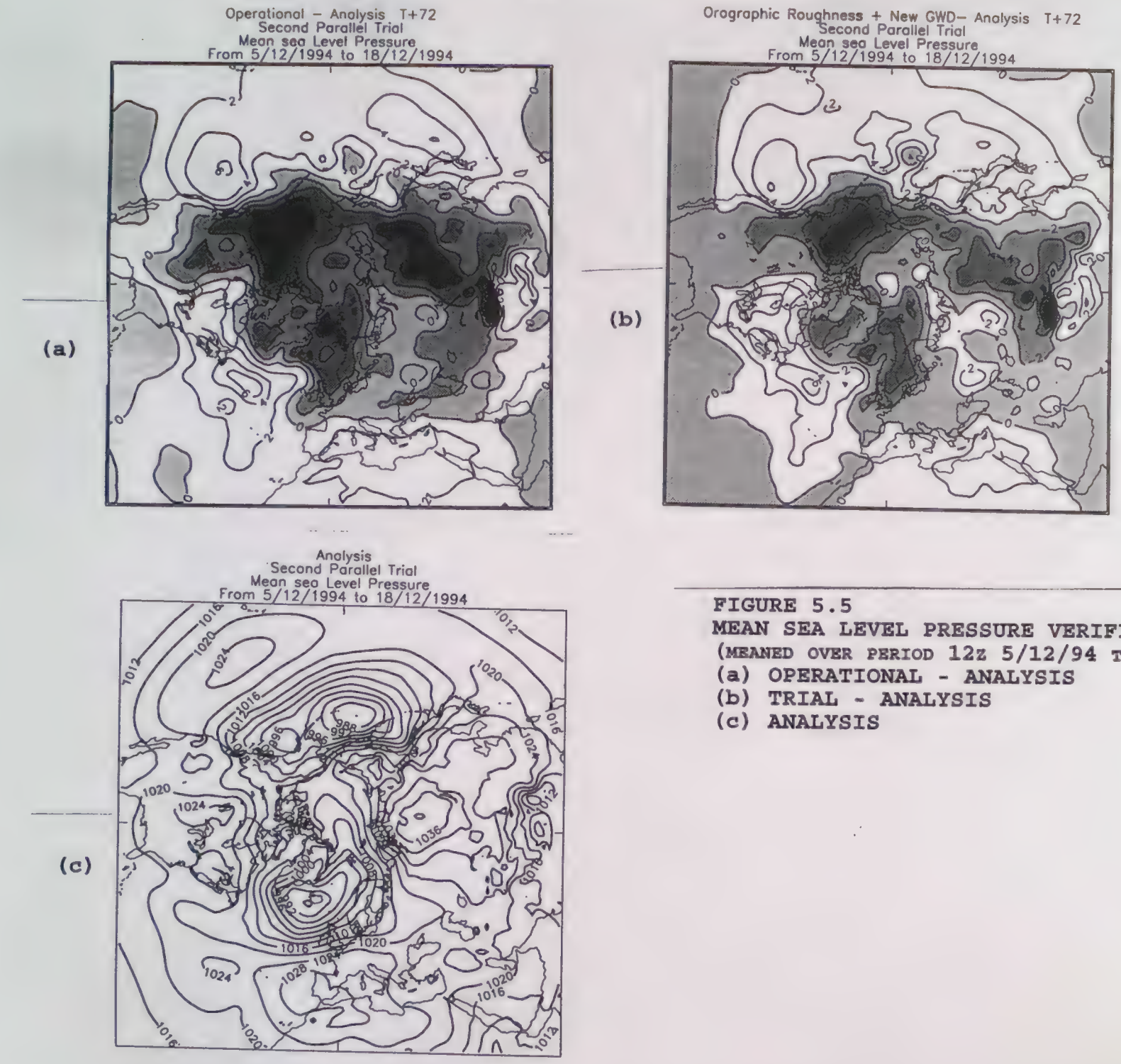
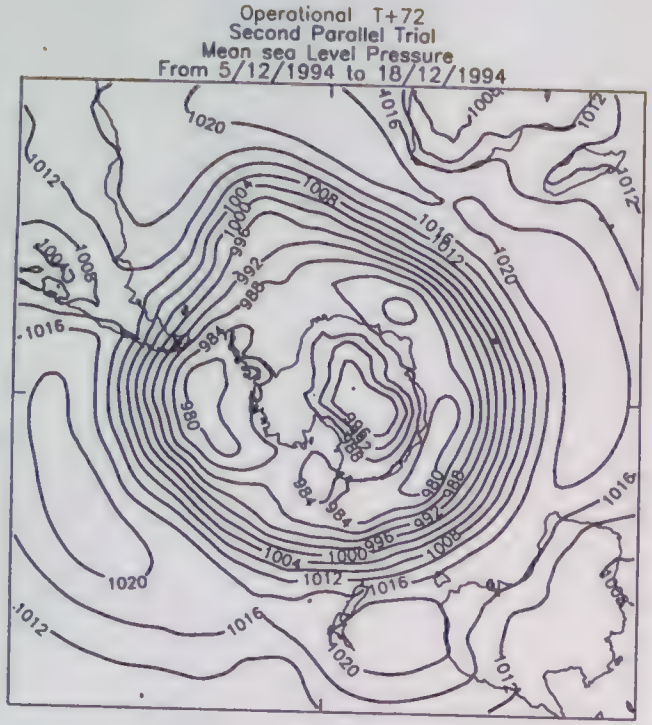
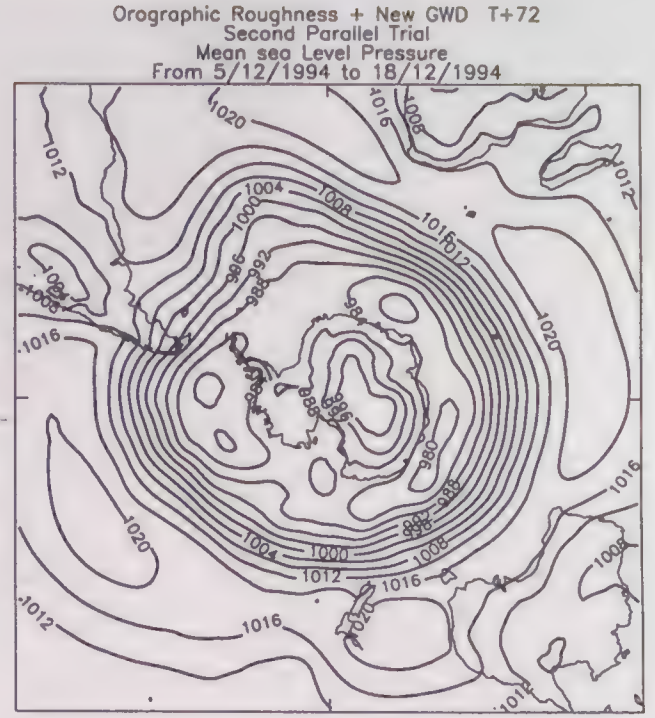


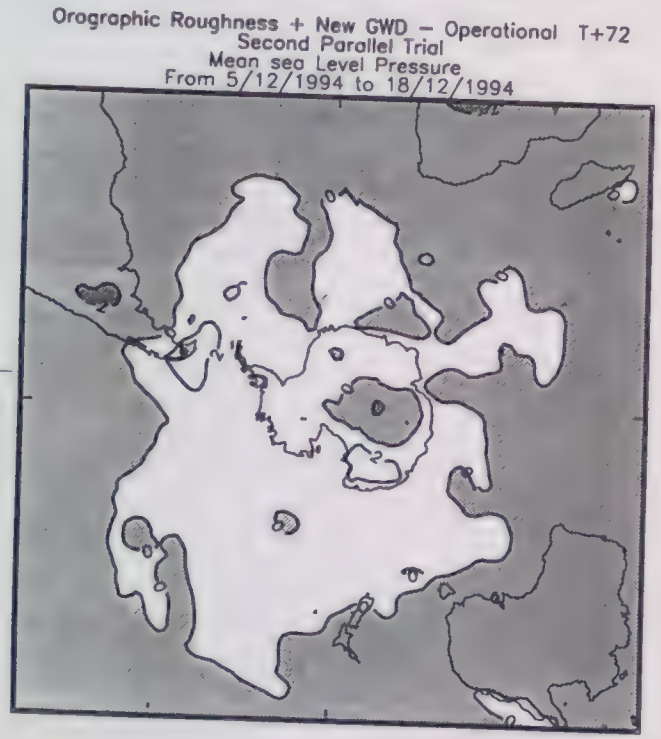
FIGURE 5.5
MEAN SEA LEVEL PRESSURE VERIFICATION T+72
(MEANED OVER PERIOD 12z 5/12/94 TO 12z 18/12/94)
(a) OPERATIONAL - ANALYSIS
(b) TRIAL - ANALYSIS
(c) ANALYSIS



(a)

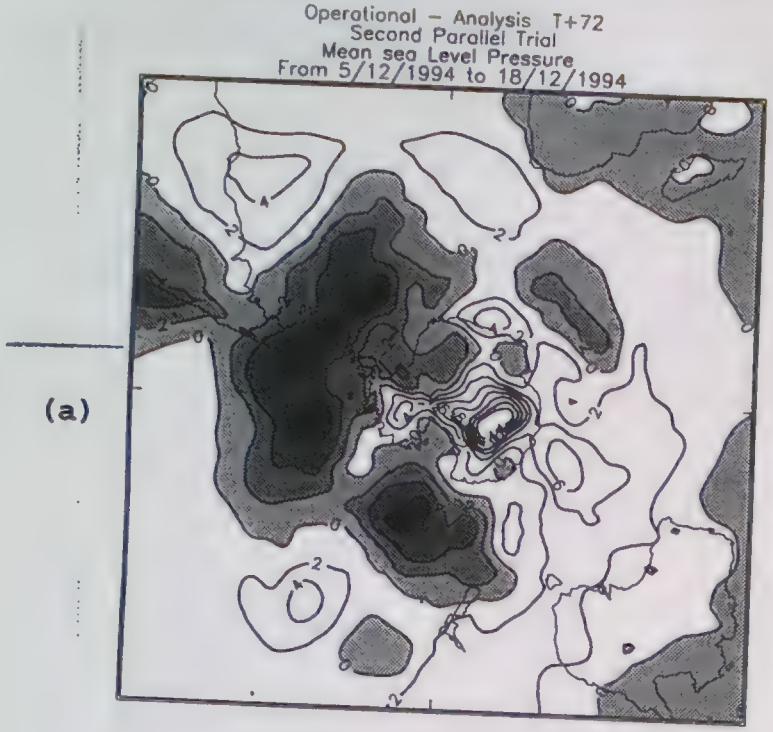


(b)

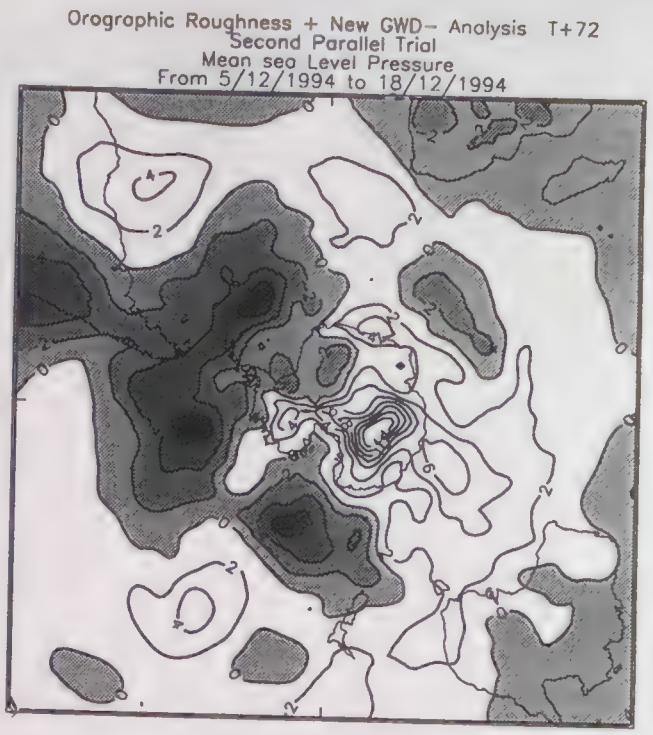


(c)

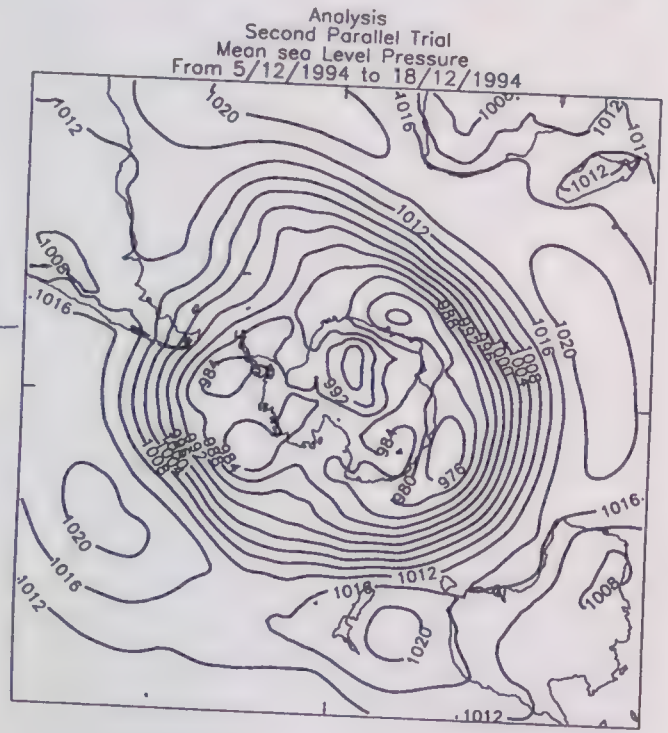
FIGURE 5.6 - SOUTHERN HEMISPHERE
MEAN SEA LEVEL PRESSURE FORECAST T+72
(MEANED OVER PERIOD 12z 5/12/94 TO 12z 18/12/94)
(a) OPERATIONAL
(b) TRIAL (NEW GRAVITY WAVE DRAG/OROGRAPHIC ROUGHNESS
(c) DIFFERENCES (TRIAL - OPERATIONAL)



(a)

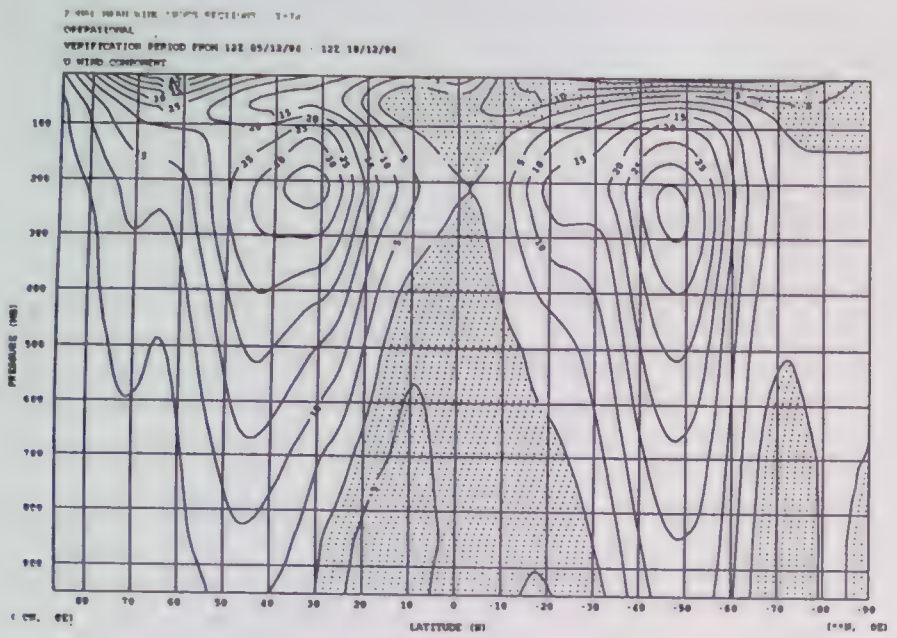


(b)

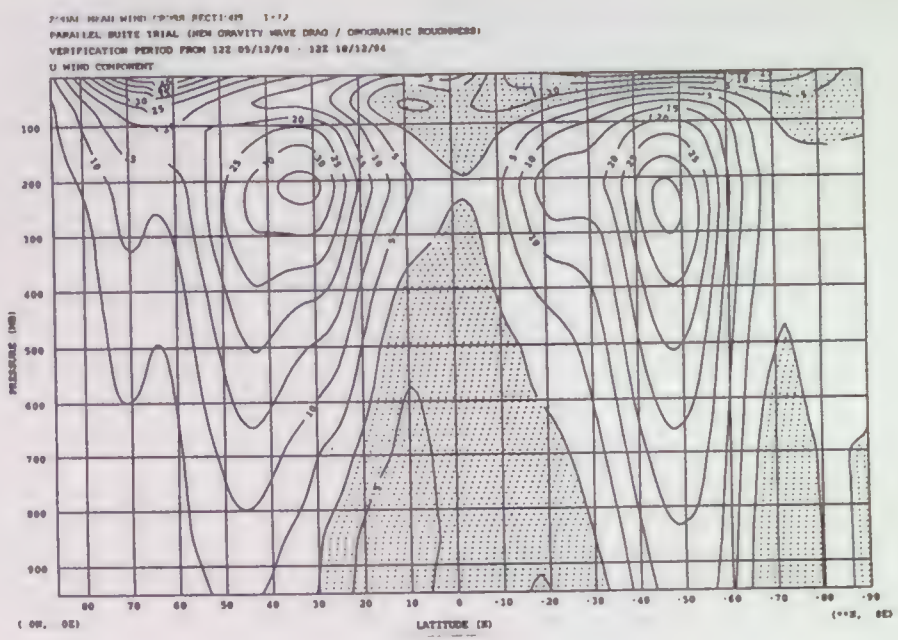


(c)

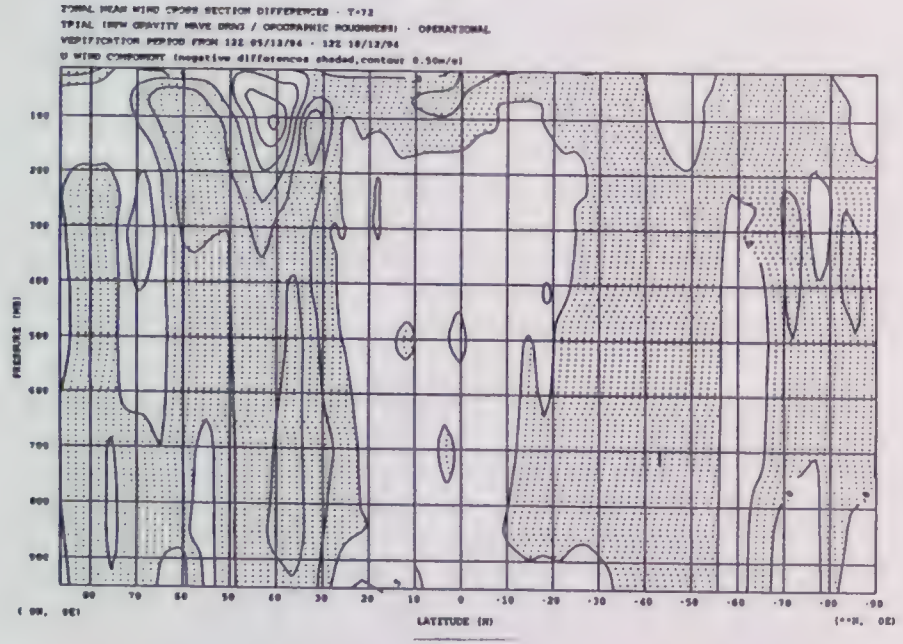
FIGURE 5.7 - SOUTHERN HEMISPHERE
MEAN SEA LEVEL PRESSURE VERIFICATION T+72
(MEANED OVER PERIOD 12z 5/12/94 TO 12z 18/12/94)
(a) OPERATIONAL - ANALYSIS
(b) TRIAL - ANALYSIS
(c) ANALYSIS



(a)

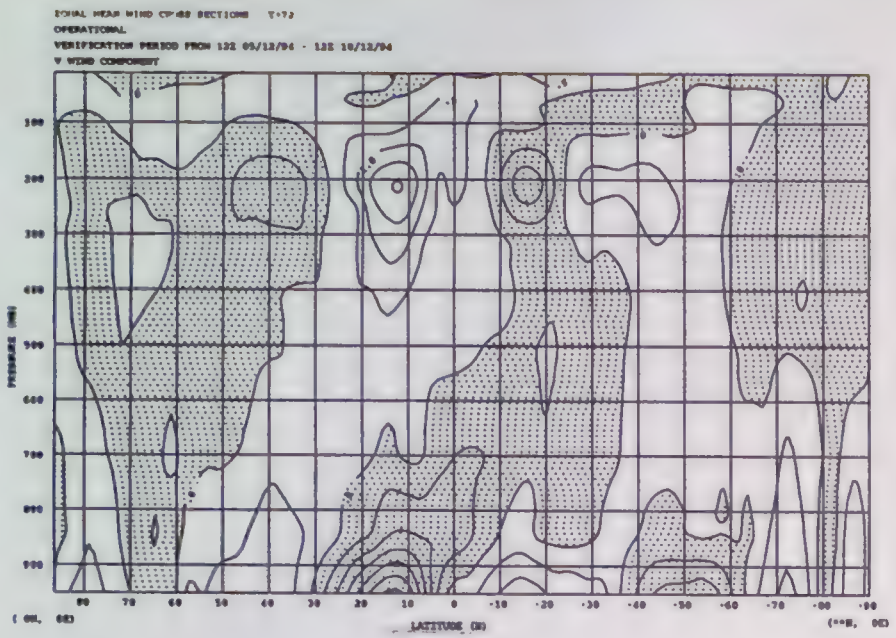


(b)

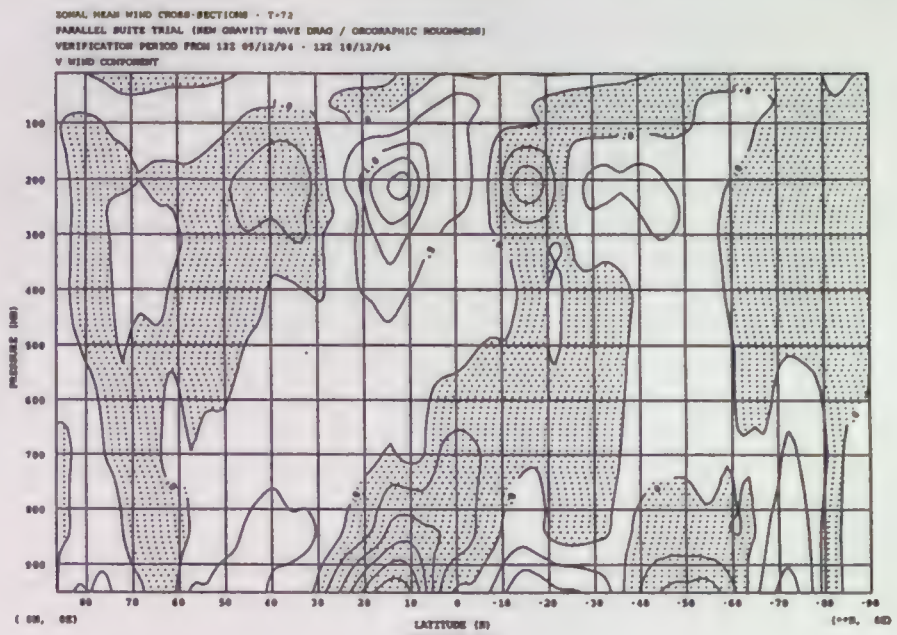


(c)

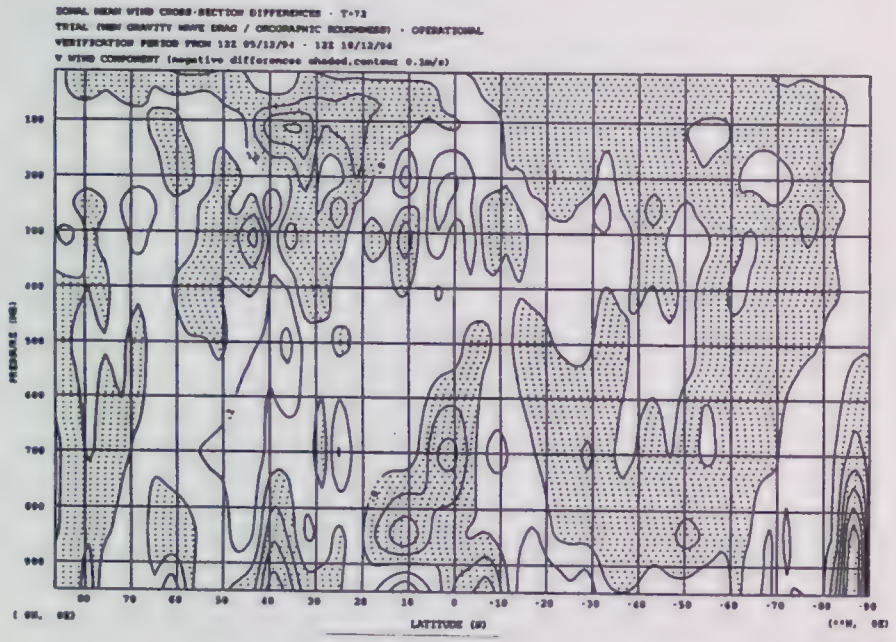
FIGURE 5.8
ZONAL MEAN CROSS-SECTIONS OF
'U' WIND COMPONENTS T+72 F/C
(a) OPERATIONAL
(b) TRIAL
(c) DIFFERENCES (TRIAL - OPERATIONAL)



(a)

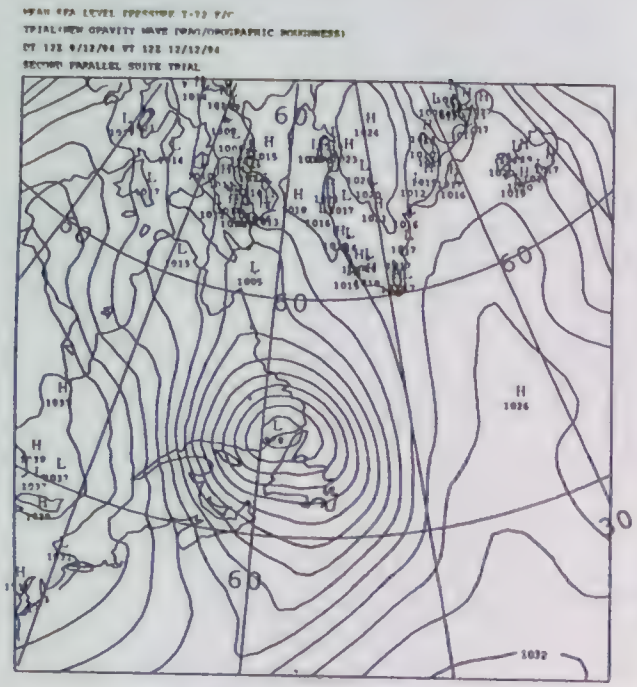


(b)

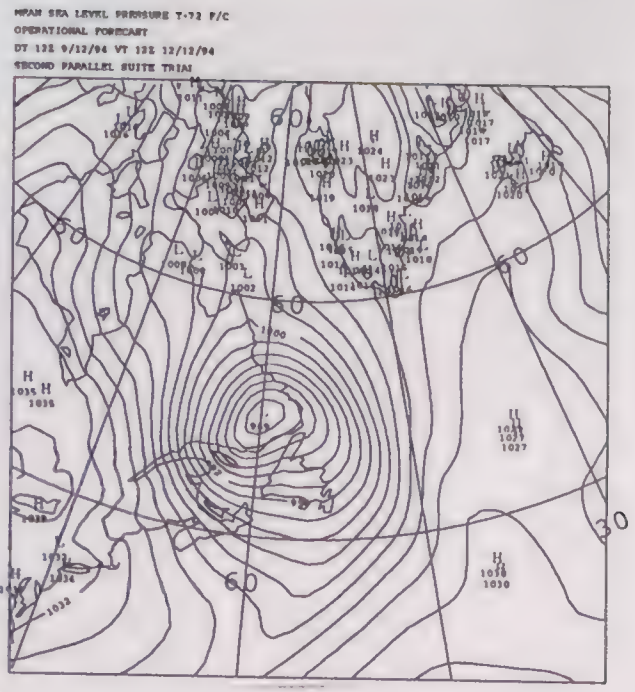


(c)

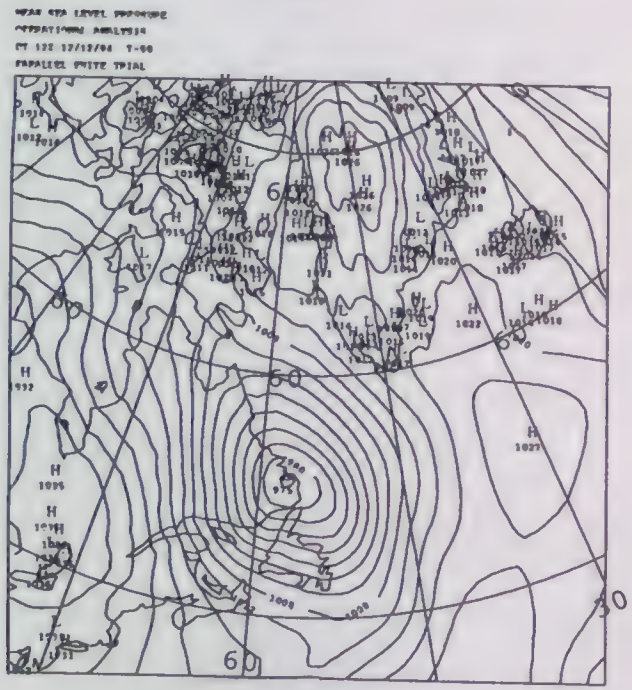
FIGURE 5.9
ZONAL MEAN CROSS-SECTIONS OF
'V' WIND COMPONENTS T+72 F/C
(a) OPERATIONAL
(b) TRIAL
(c) DIFFERENCES (TRIAL - OPERATIONAL)



(a)

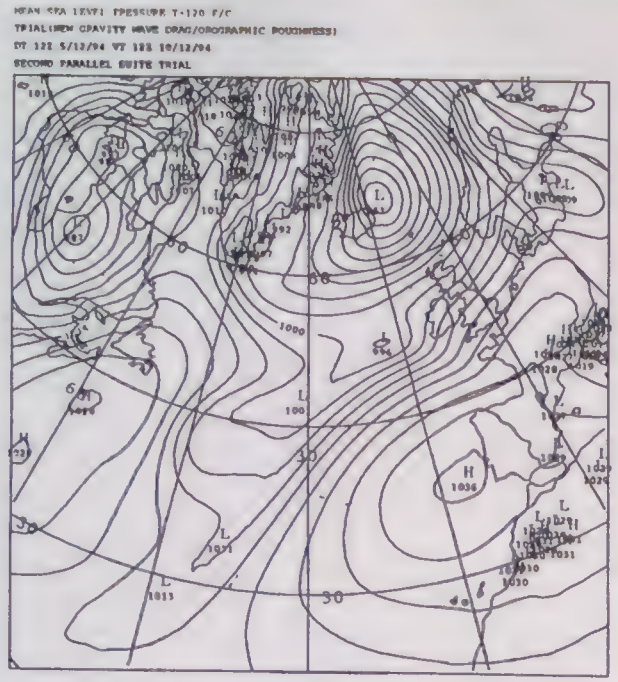


(b)

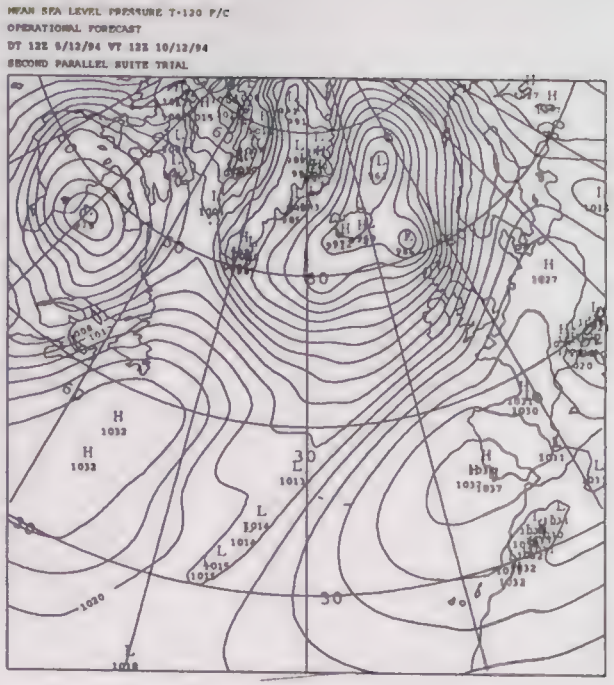


(c)

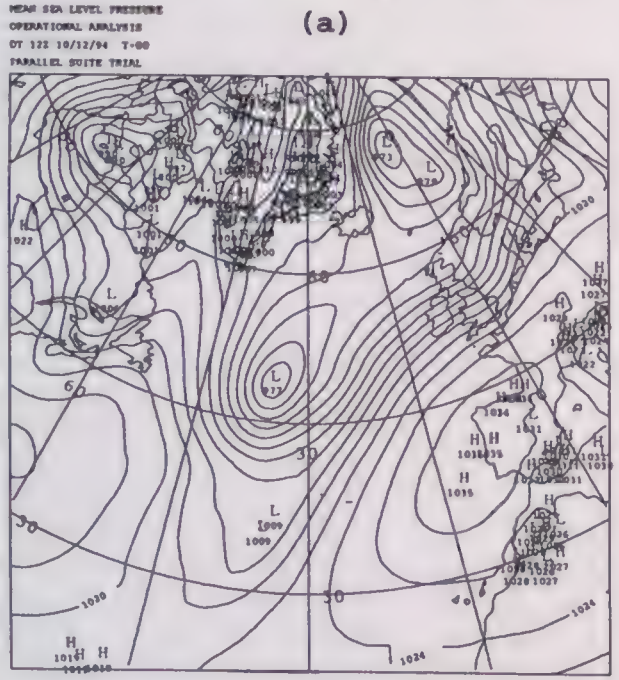
FIGURE 5.10
MEAN SEA LEVEL PRESSURE T+72 F/C
DT12Z 9/12/94 VT 12Z 12/12/94
(a) TRIAL
(b) OPERATIONAL
(c) ANALYSIS 12Z 12/12/94



(a)

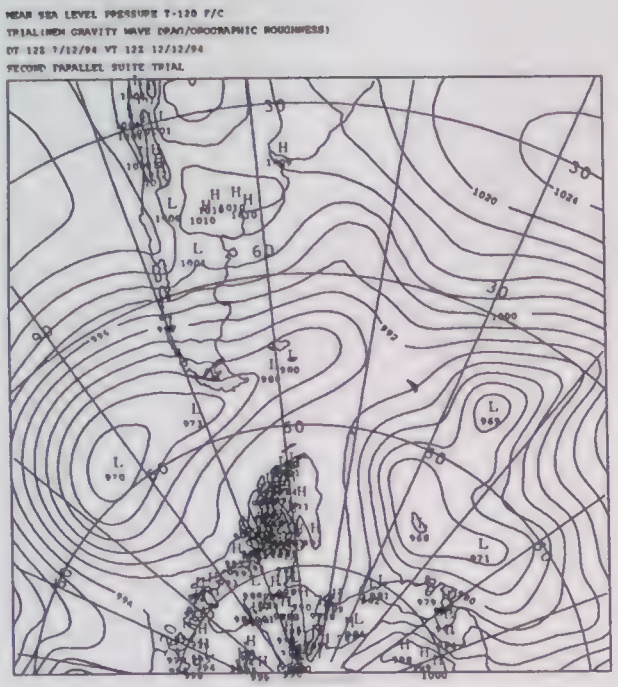


(b)

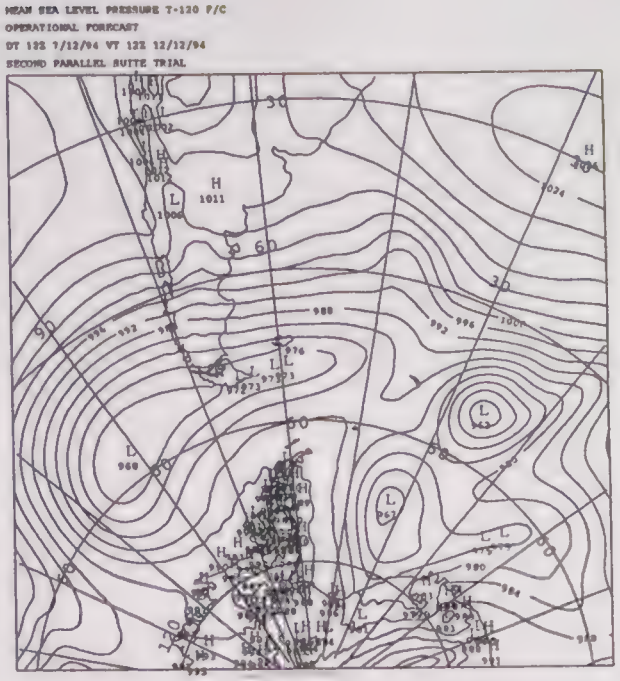


(c)

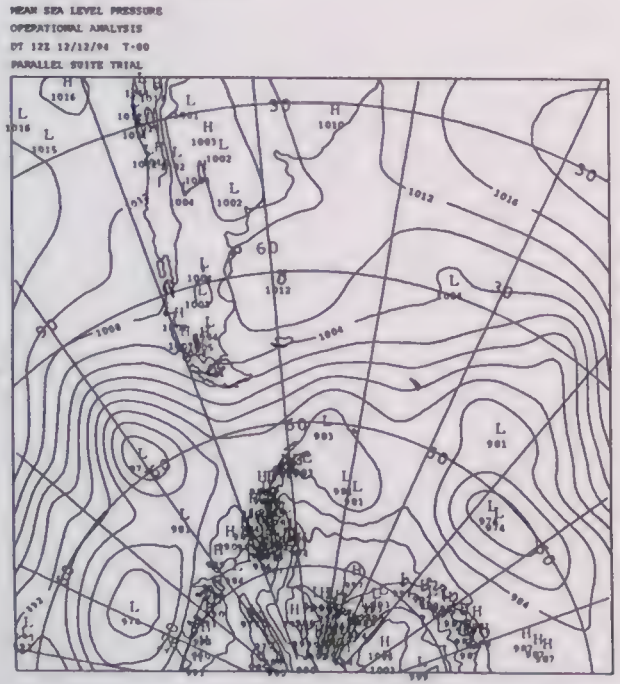
FIGURE 5.11
MEAN SEA LEVEL PRESSURE T+120 F/C
DT12Z 5/12/94 VT 12Z 10/12/94
(a) TRIAL
(b) OPERATIONAL
(c) ANALYSIS 12Z 10/12/94



(a)



(b)



(c)

FIGURE 5.12 - SOUTHERN HEMISPHERE MEAN SEA LEVEL PRESSURE T+120 F/C DT12Z 7/12/94 VT 12Z 12/12/94

(a) TRIAL

(b) OPERATIONAL

(c) ANALYSIS 12Z 10/12/94

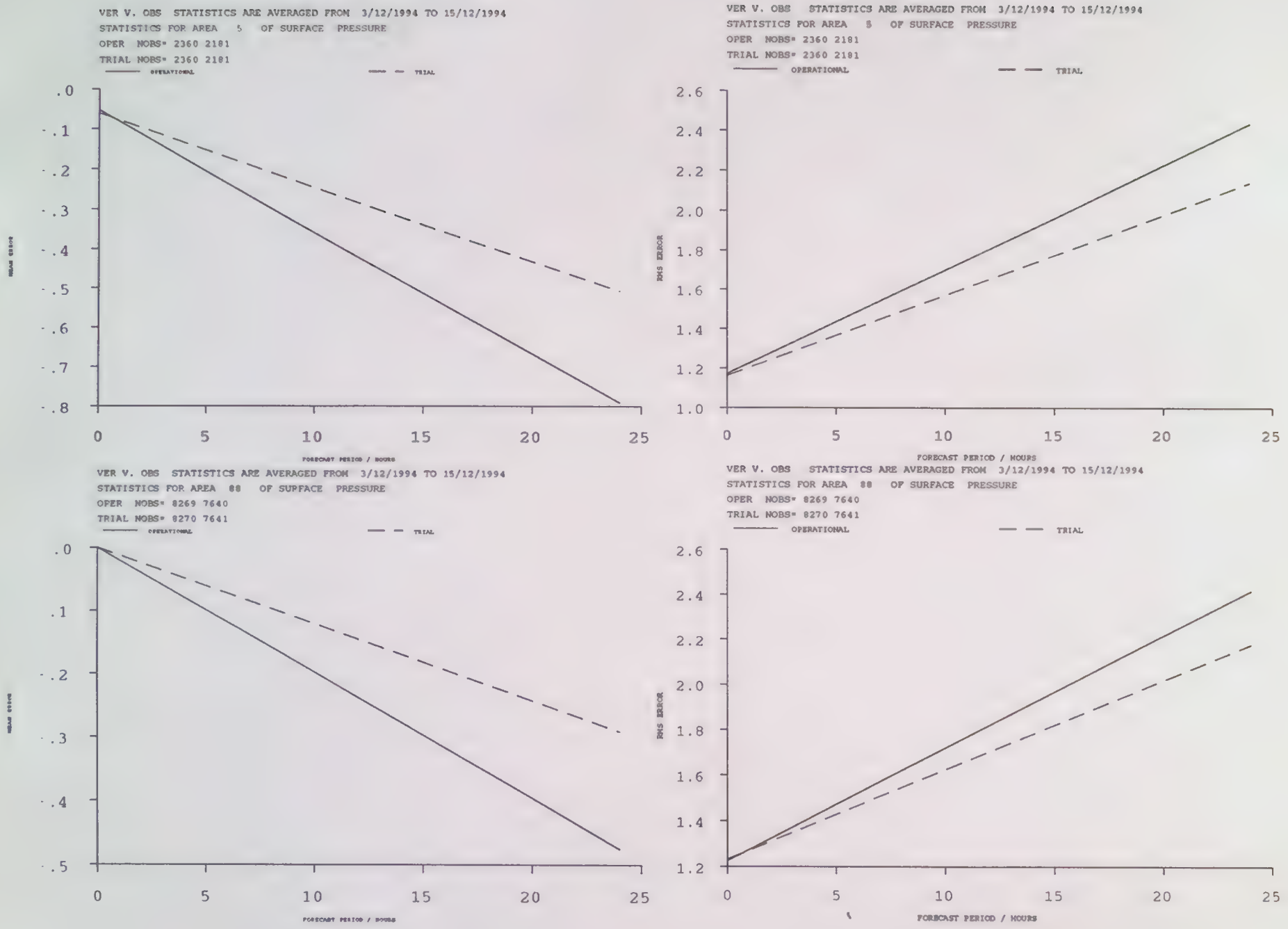

VER V. OBS STATISTICS ARE AVERAGED FROM 3/12/1994 TO 15/12/1994
STATISTICS FOR AREA 5 OF SURFACE PRESSURE
OPER NOBS= 2360 2181
TRIAL NOBS= 2360 2181
OPERATIONAL
TRIAL
MEAN ERROR
.0
-.1
-.2
-.3
-.4
-.5
-.6
-.7
-.8
0
5
10
15
20
25
FORECAST PERIOD / HOURS
VER V. OBS STATISTICS ARE AVERAGED FROM 3/12/1994 TO 15/12/1994
STATISTICS FOR AREA 5 OF SURFACE PRESSURE
OPER NOBS= 2360 2181
TRIAL NOBS= 2360 2181
OPERATIONAL
TRIAL
RMS ERROR
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0
5
10
15
20
25
FORECAST PERIOD / HOURS
VER V. OBS STATISTICS ARE AVERAGED FROM 3/12/1994 TO 15/12/1994
STATISTICS FOR AREA 88 OF SURFACE PRESSURE
OPER NOBS= 8269 7640
TRIAL NOBS= 8270 7641
OPERATIONAL
TRIAL
MEAN ERROR
.0
.1
-.2
-.3
-.4
-.5
0
5
10
15
20
25
FORECAST PERIOD / HOURS
VER V. OBS STATISTICS ARE AVERAGED FROM 3/12/1994 TO 15/12/1994
STATISTICS FOR AREA 88 OF SURFACE PRESSURE
OPER NOBS= 8269 7640
TRIAL NOBS= 8270 7641
OPERATIONAL
TRIAL
RMS ERROR
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
0
5
10
15
20
25
FORECAST PERIOD / HOURS

FIGURE 6.1

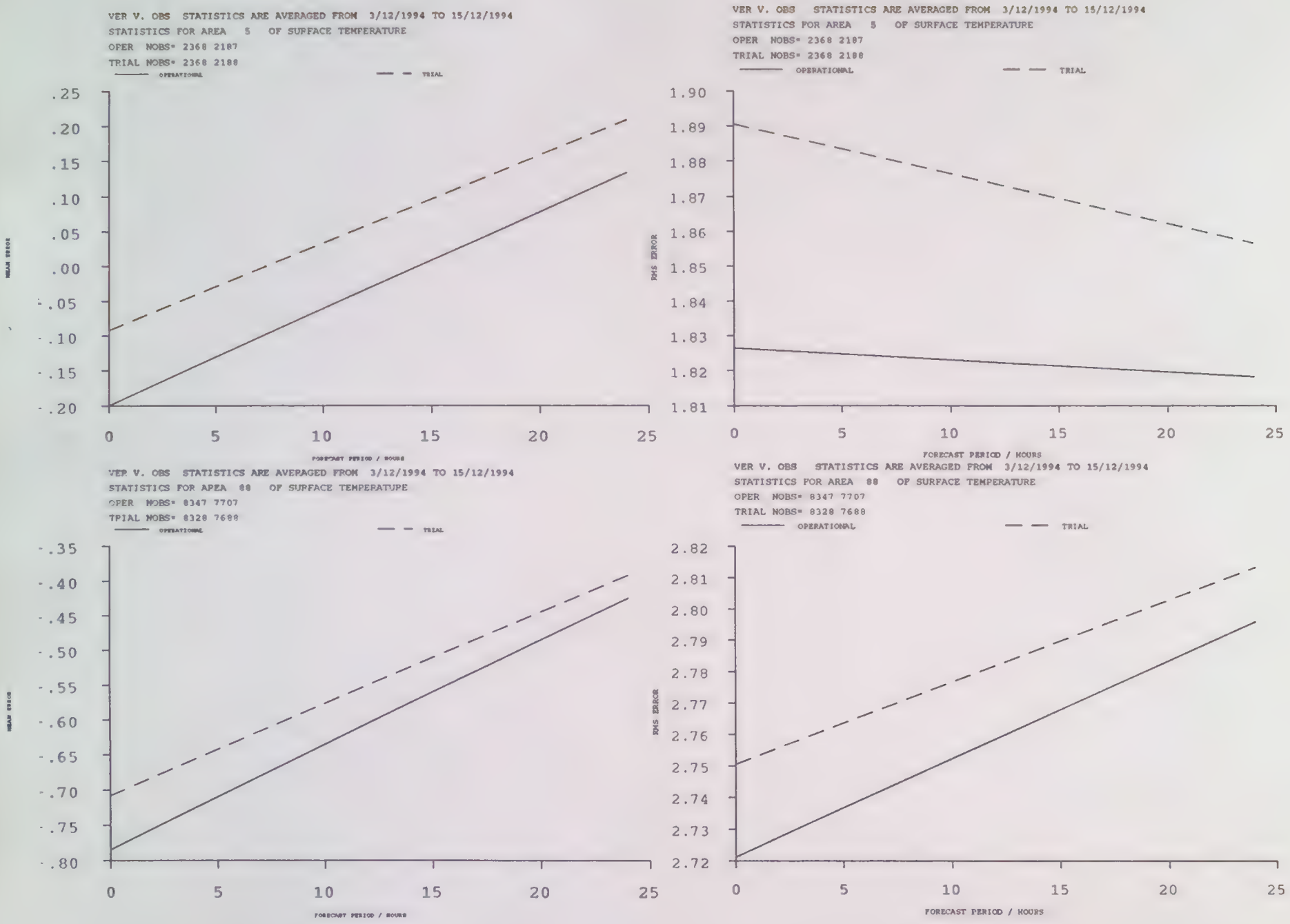

VER V. OBS STATISTICS ARE AVERAGED FROM 3/12/1994 TO 15/12/1994
STATISTICS FOR AREA 5 OF SURFACE TEMPERATURE
OPER NOBS= 2368 2187
TRIAL NOBS= 2368 2188
OPERATIONAL
TRIAL
MEAN ERROR
.25
.20
.15
.10
.05
.00
-.05
-.10
-.15
-.20
0
5
10
15
20
25
FORECAST PERIOD / HOURS
VER V. OBS STATISTICS ARE AVERAGED FROM 3/12/1994 TO 15/12/1994
STATISTICS FOR AREA 5 OF SURFACE TEMPERATURE
OPER NOBS= 2368 2187
TRIAL NOBS= 2368 2188
OPERATIONAL
TRIAL
RMS ERROR
1.90
1.89
1.88
1.87
1.86
1.85
1.84
1.83
1.82
1.81
0
5
10
15
20
25
FORECAST PERIOD / HOURS
VER V. OBS STATISTICS ARE AVERAGED FROM 3/12/1994 TO 15/12/1994
STATISTICS FOR AREA 88 OF SURFACE TEMPERATURE
OPER NOBS= 8347 7707
TRIAL NOBS= 8328 7688
OPERATIONAL
TRIAL
MEAN ERROR
-.35
-.40
-.45
-.50
-.55
-.60
-.65
-.70
-.75
-.80
0
5
10
15
20
25
FORECAST PERIOD / HOURS
VER V. OBS STATISTICS ARE AVERAGED FROM 3/12/1994 TO 15/12/1994
STATISTICS FOR AREA 88 OF SURFACE TEMPERATURE
OPER NOBS= 8347 7707
TRIAL NOBS= 8328 7688
OPERATIONAL
TRIAL
RMS ERROR
2.82
2.81
2.80
2.79
2.78
2.77
2.76
2.75
2.74
2.73
2.72
0
5
10
15
20
25
FORECAST PERIOD / HOURS

FIGURE 6.2

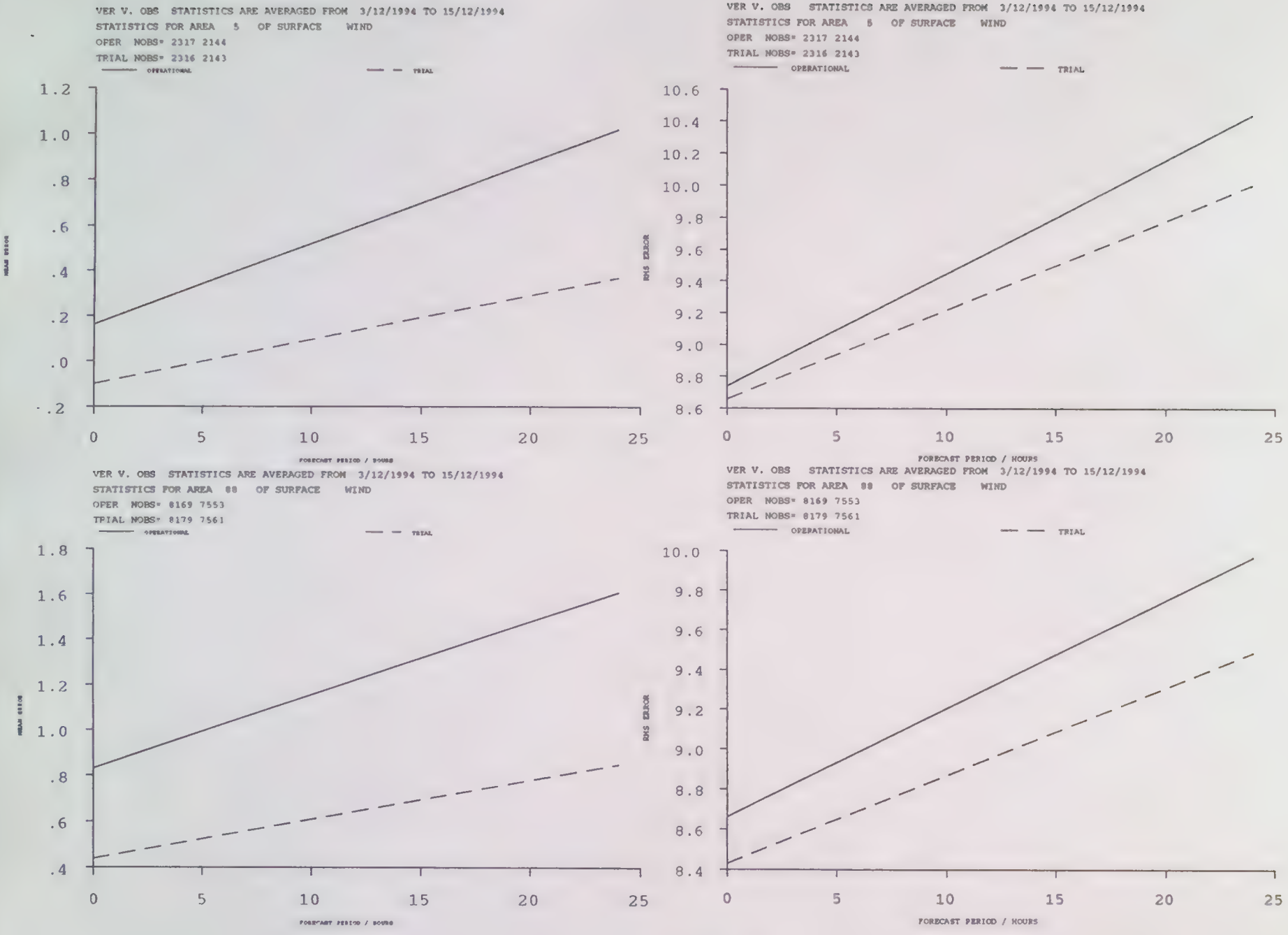
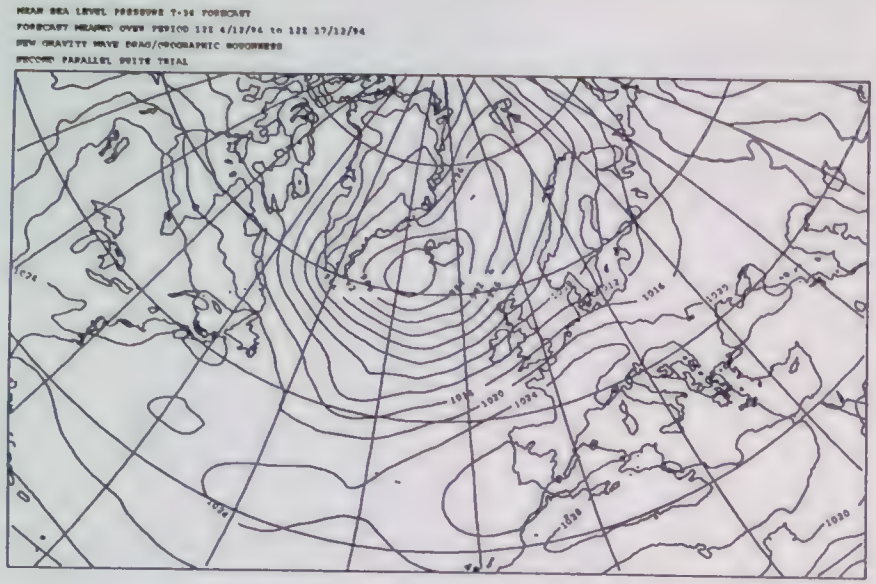
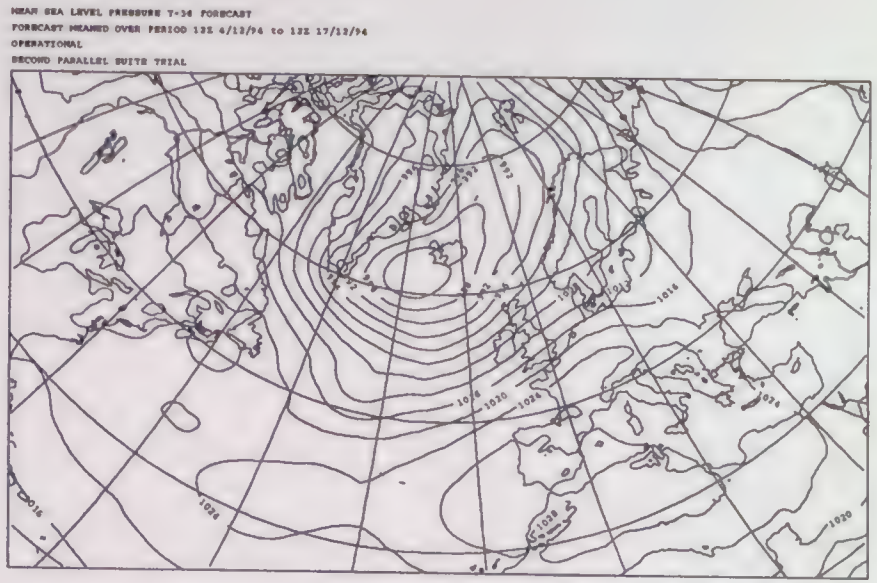

VER V. OBS STATISTICS ARE AVERAGED FROM 3/12/1994 TO 15/12/1994
STATISTICS FOR AREA 5 OF SURFACE WIND
OPER NOBS= 2317 2144
TRIAL NOBS= 2316 2143
OPERATIONAL
TRIAL
1.2
1.0
.8
.6
.4
.2
.0
-.2
0
5
10
15
20
25
FORECAST PERIOD / HOURS
VER V. OBS STATISTICS ARE AVERAGED FROM 3/12/1994 TO 15/12/1994
STATISTICS FOR AREA 5 OF SURFACE WIND
OPER NOBS= 2317 2144
TRIAL NOBS= 2316 2143
OPERATIONAL
TRIAL
10.6
10.4
10.2
10.0
9.8
9.6
9.4
9.2
9.0
8.8
8.6
RMS ERROR
0
5
10
15
20
25
FORECAST PERIOD / HOURS
VER V. OBS STATISTICS ARE AVERAGED FROM 3/12/1994 TO 15/12/1994
STATISTICS FOR AREA 88 OF SURFACE WIND
OPER NOBS= 8169 7553
TRIAL NOBS= 8179 7561
OPERATIONAL
TRIAL
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
0
5
10
15
20
25
VER V. OBS STATISTICS ARE AVERAGED FROM 3/12/1994 TO 15/12/1994
STATISTICS FOR AREA 88 OF SURFACE WIND
OPER NOBS= 8169 7553
TRIAL NOBS= 8179 7561
OPERATIONAL
TRIAL
10.0
9.8
9.6
9.4
9.2
9.0
8.8
8.6
8.4
RMS ERROR
0
5
10
15
20
25
FORECAST PERIOD / HOURS

FIGURE 6.3

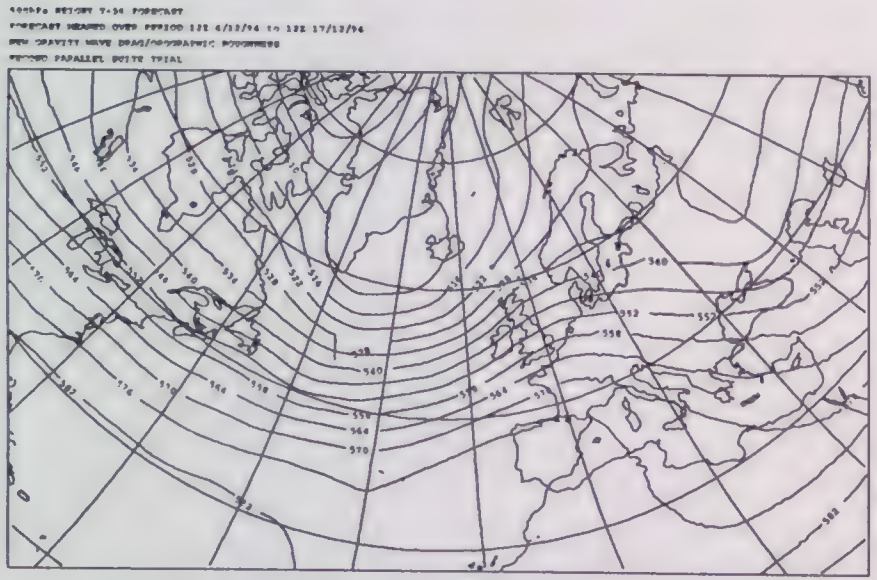
FIGURE 7.1
MEAN SEA LEVEL PRESSURE / 500hPa T+36 F/C
MEANED OVER PERIOD 12Z 4/12/94 - 12Z 17/12/94



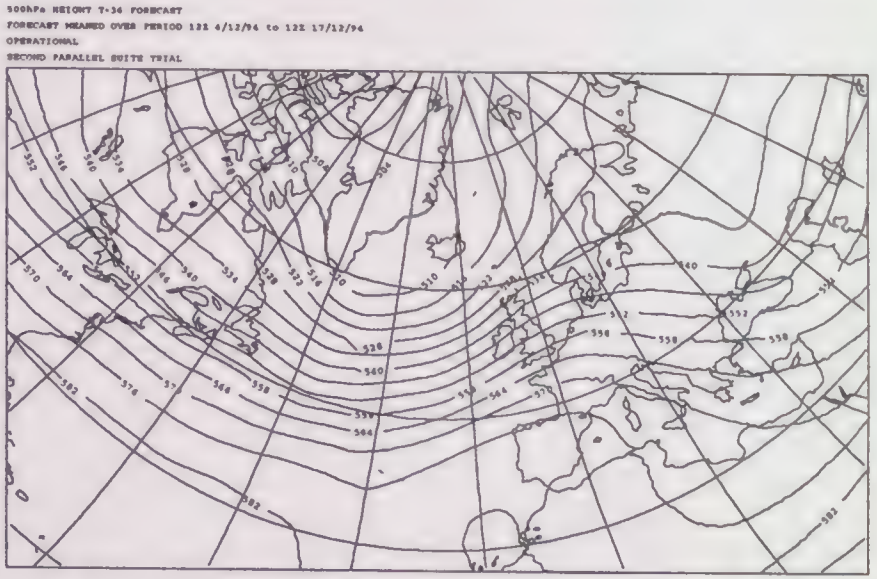
(a) TRIAL



(b) OPERATIONAL

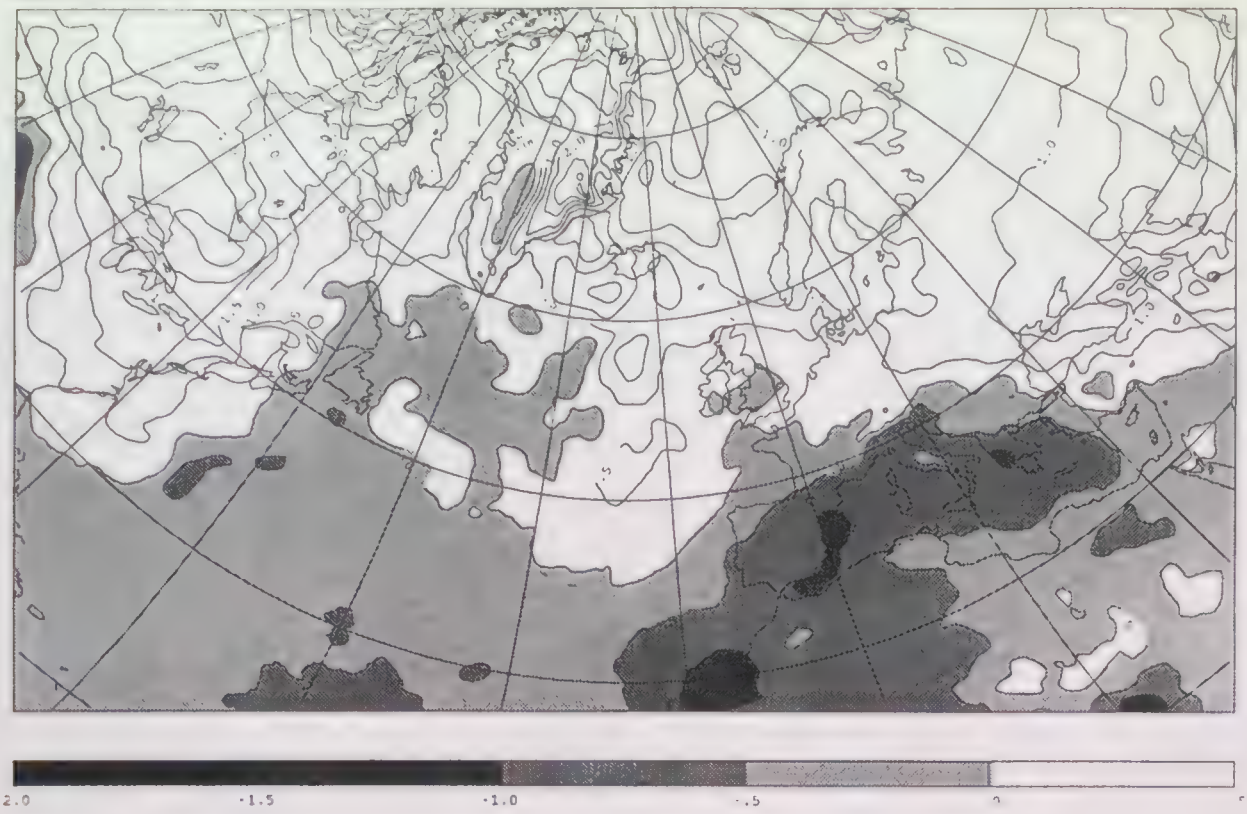


(c) TRIAL



(d) OPERATIONAL

(a)



(b)

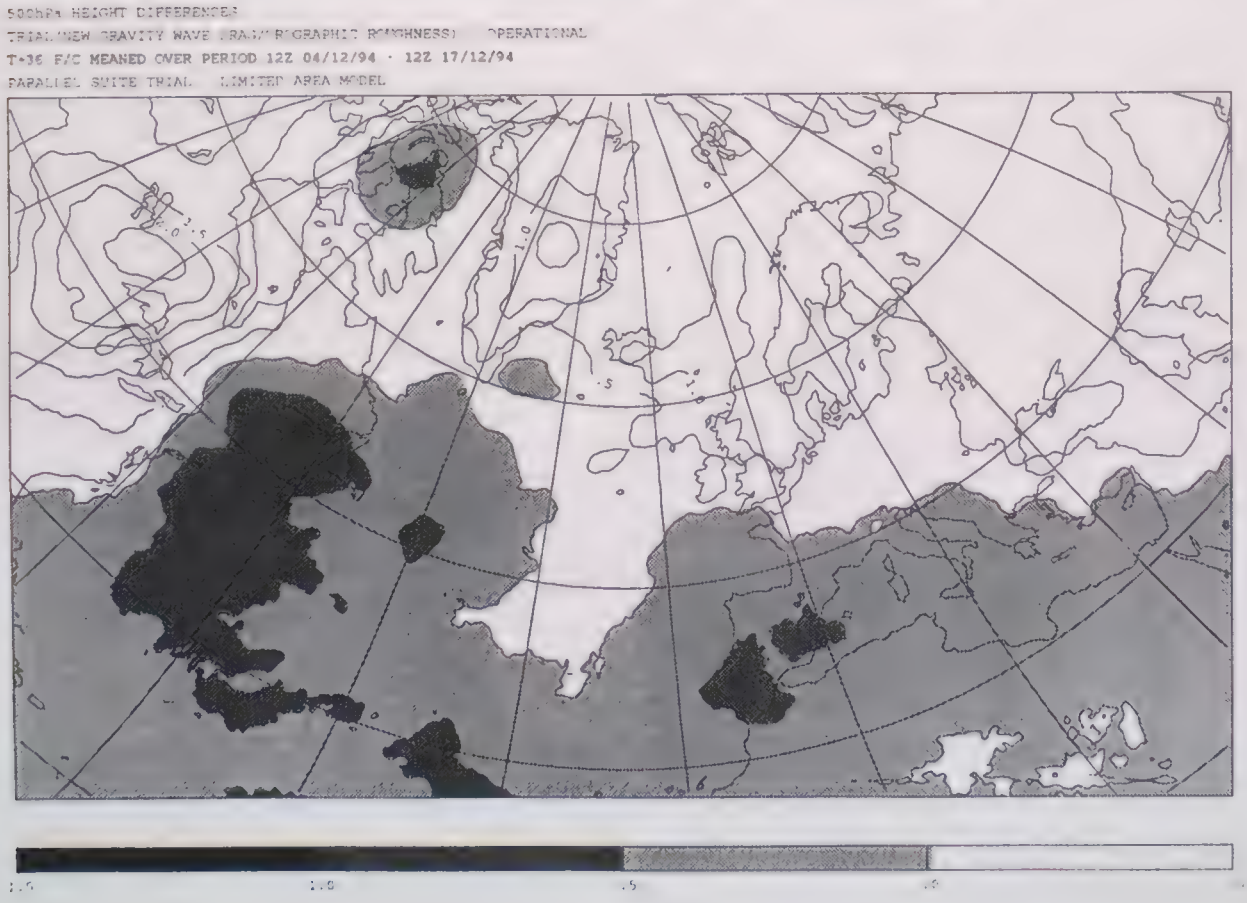
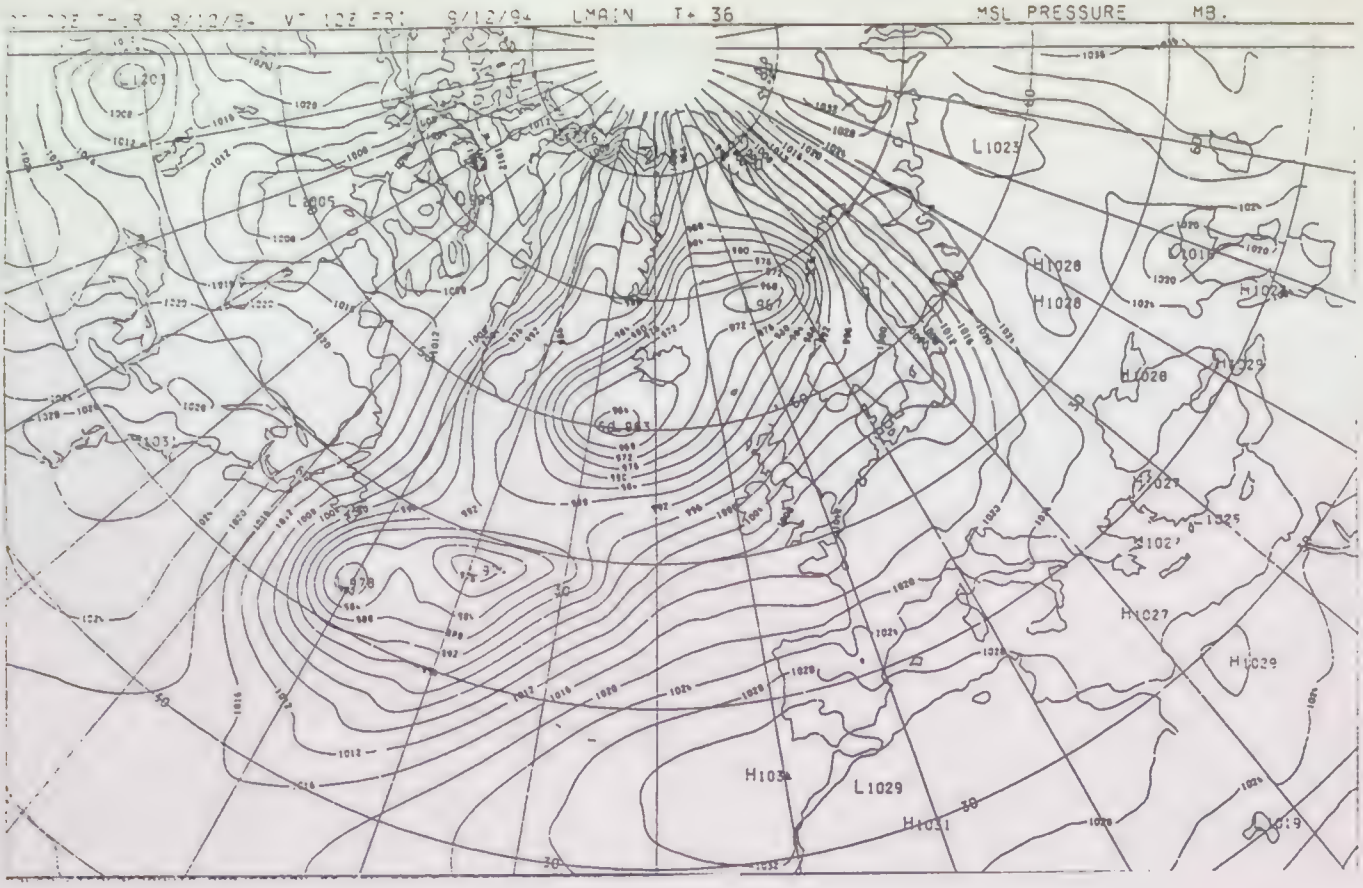
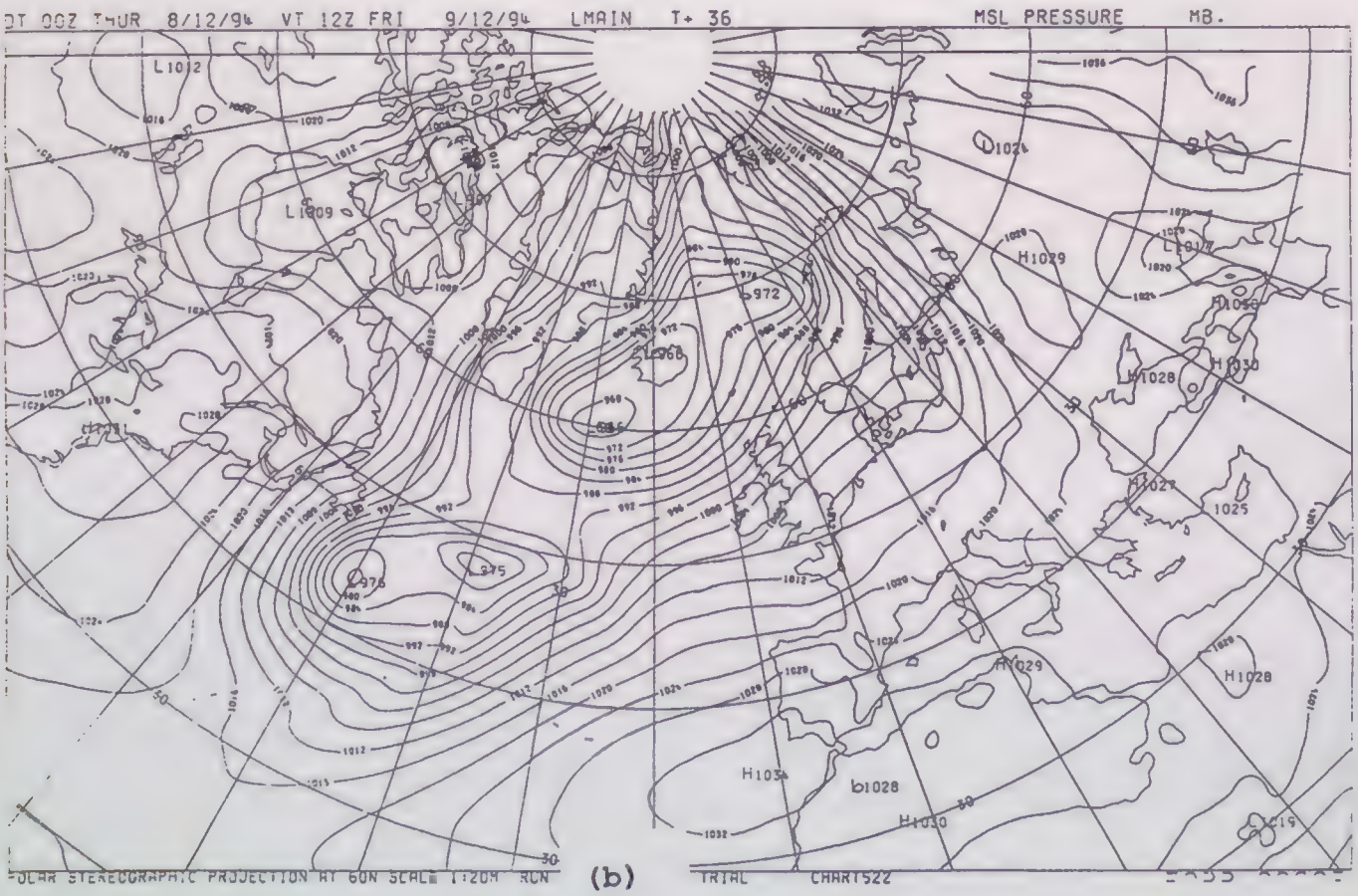


FIGURE 7.2
(a) MEAN SEA LEVEL PRESSURE DIFFERENCES T+36
(TRIAL - OPERATIONAL)
(b) 500hPa DIFFERENCES T+36
(TRIAL - OPERATIONAL)

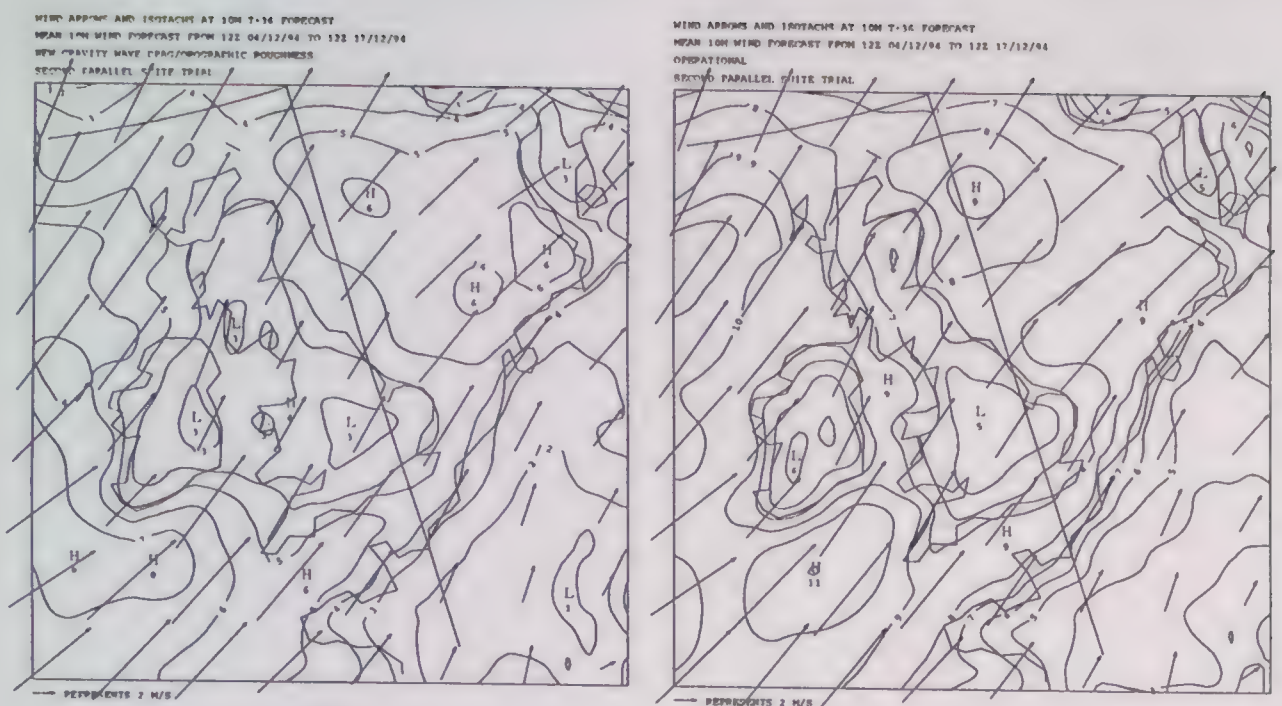


(a)



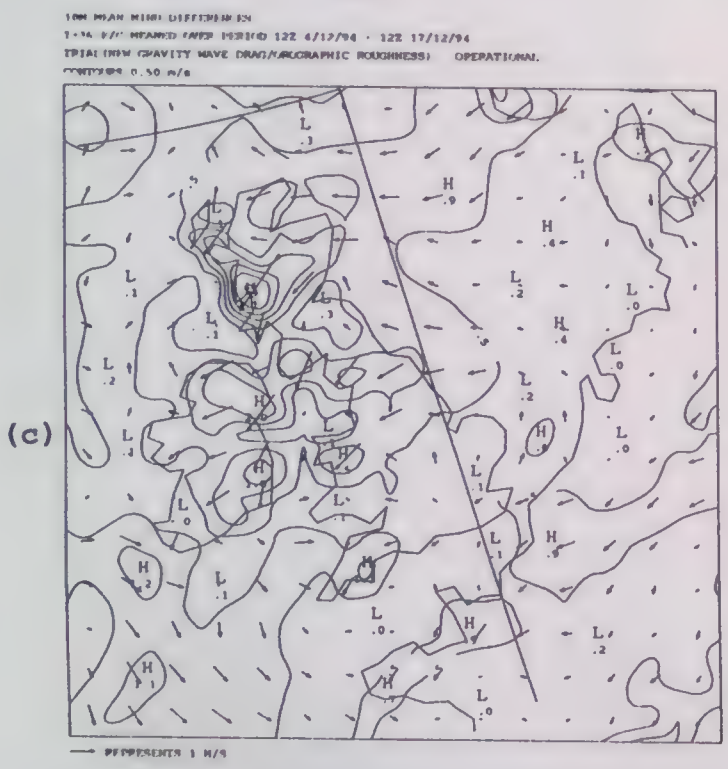
(b)

FIGURE 7.3 - MEAN SEA LEVEL PRESSURE
T+36 F/C DT00Z 8/12/96 VT 12Z 9/12/96
(a) OPERATIONAL
(b) TRIAL



(a)

(b)



(c)

FIGURE 7.4
10M WIND T+36 F/C
MEANED FROM 12Z 4/12/94 TO 12Z 17/12/94
(a) TRIAL
(b) OPERATIONAL
(c) DIFFERENCES (TRIAL - OPERATIONAL)

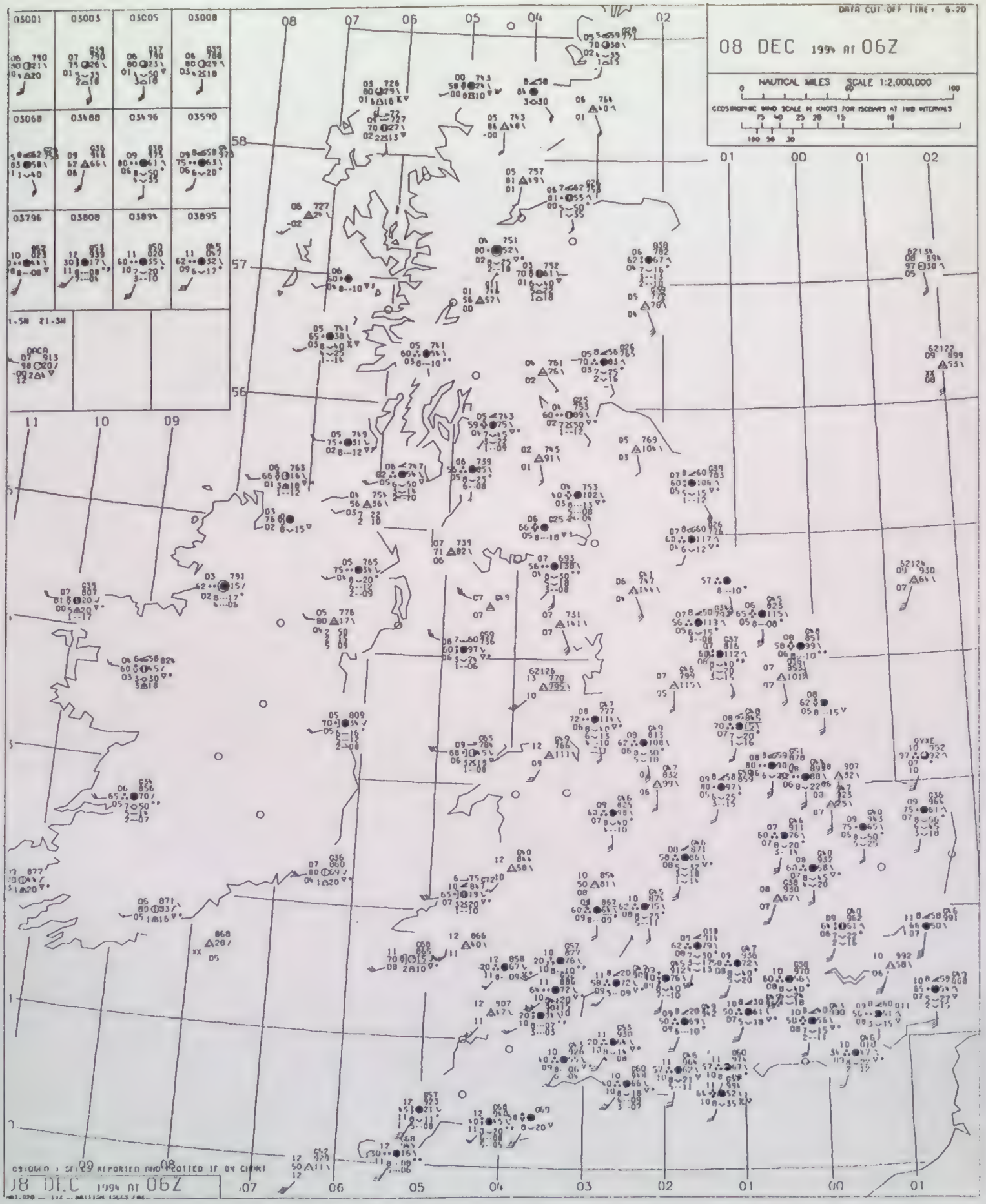


FIGURE 7.5
OBSERVATIONS FOR 06Z 8/12/94

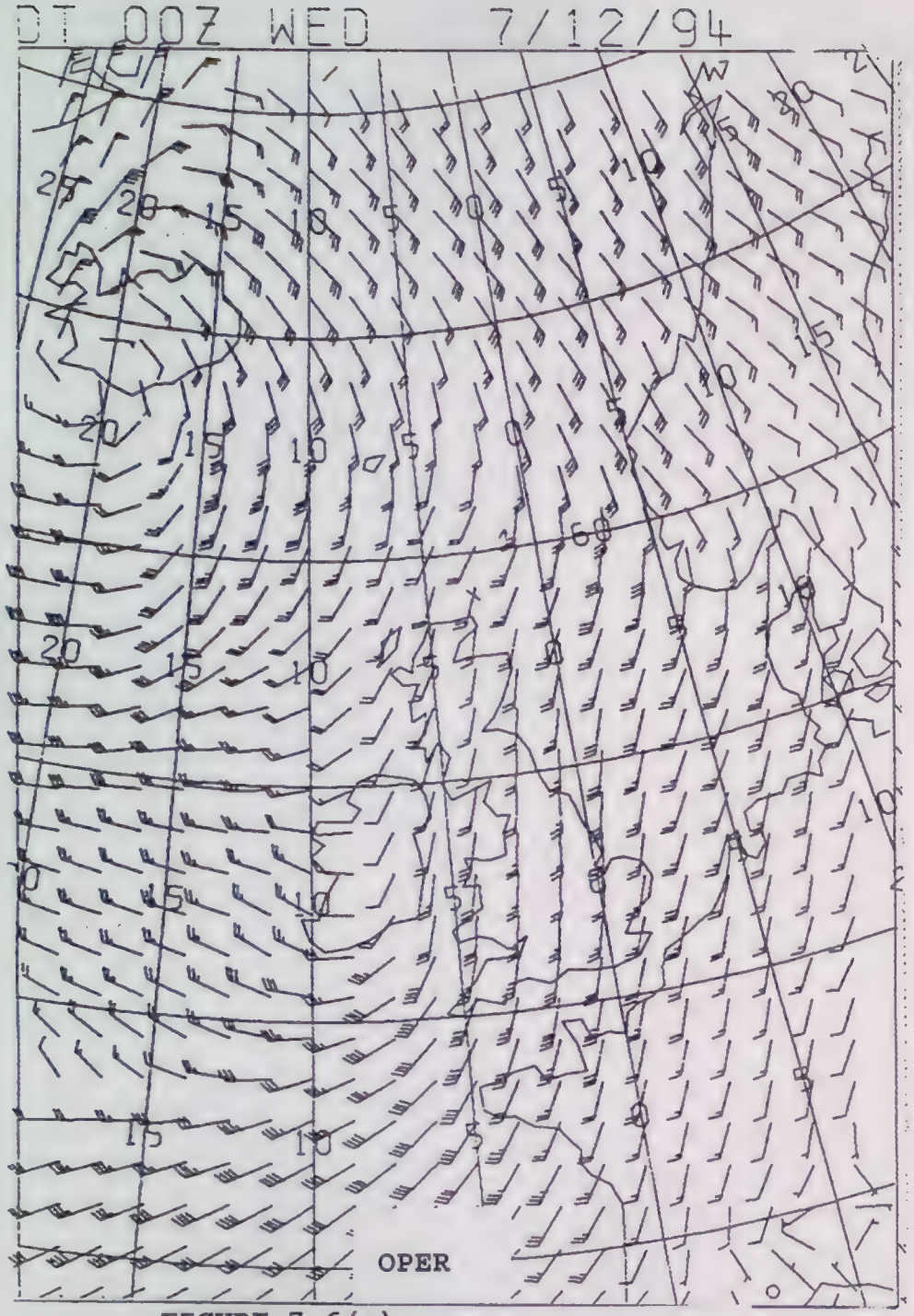


FIGURE 7.6(a)
10M WIND T+30 F/C VT 06Z 8/12/94

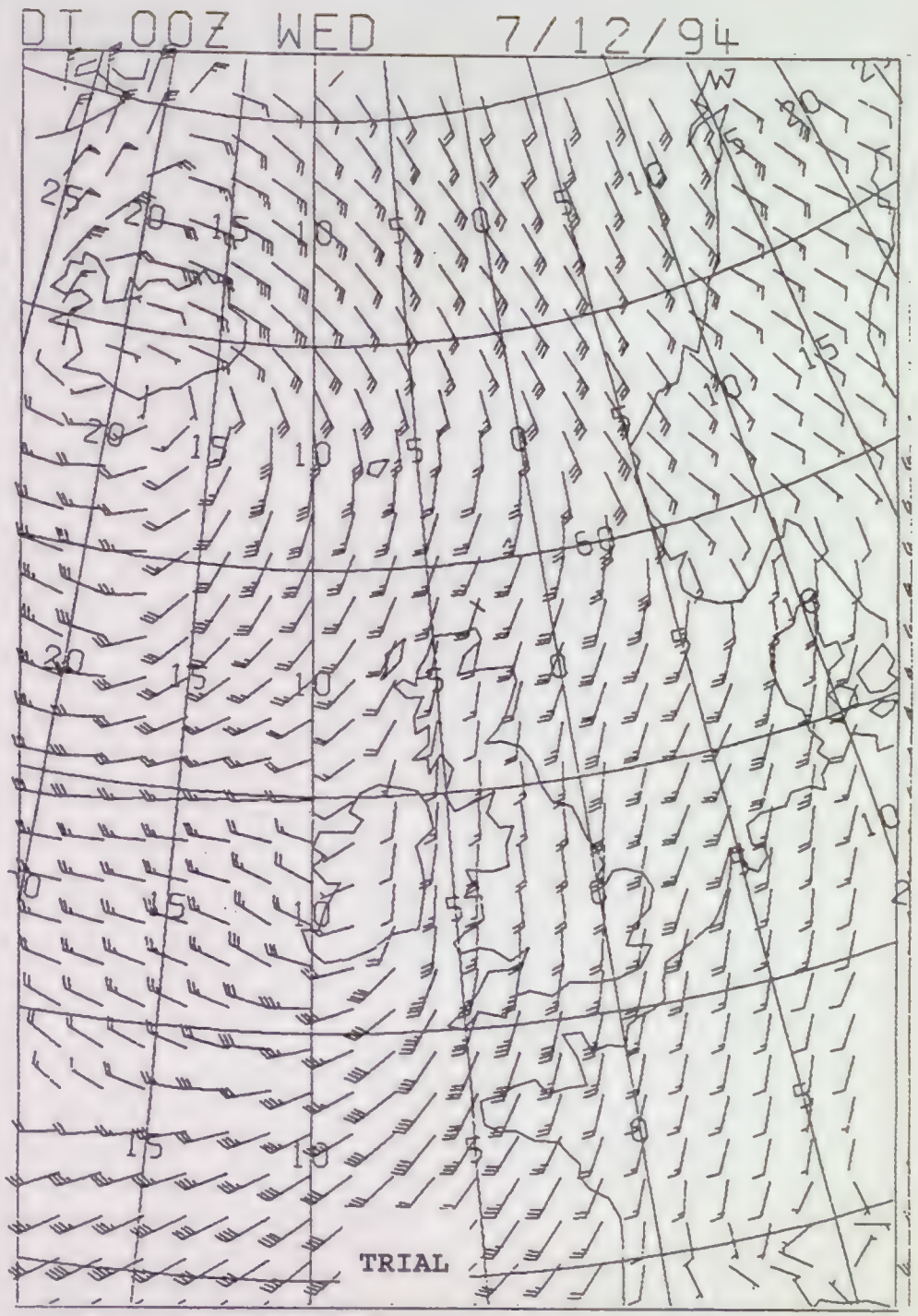


FIGURE 7.6(b)
10M WIND T+30 F/C VT 06Z 8/12/94

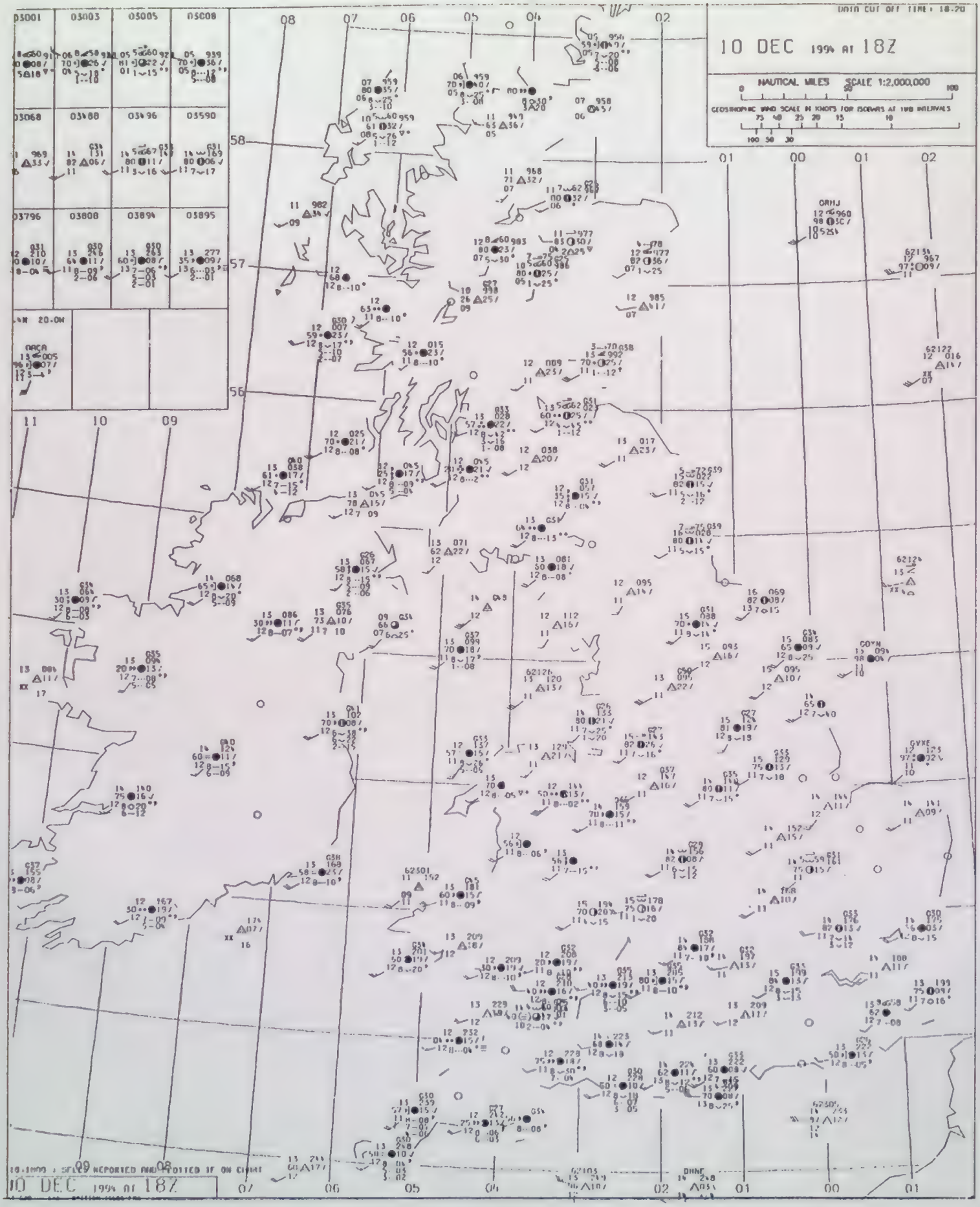


FIGURE 7.7
OBSERVATIONS FOR 18Z 10/12/94

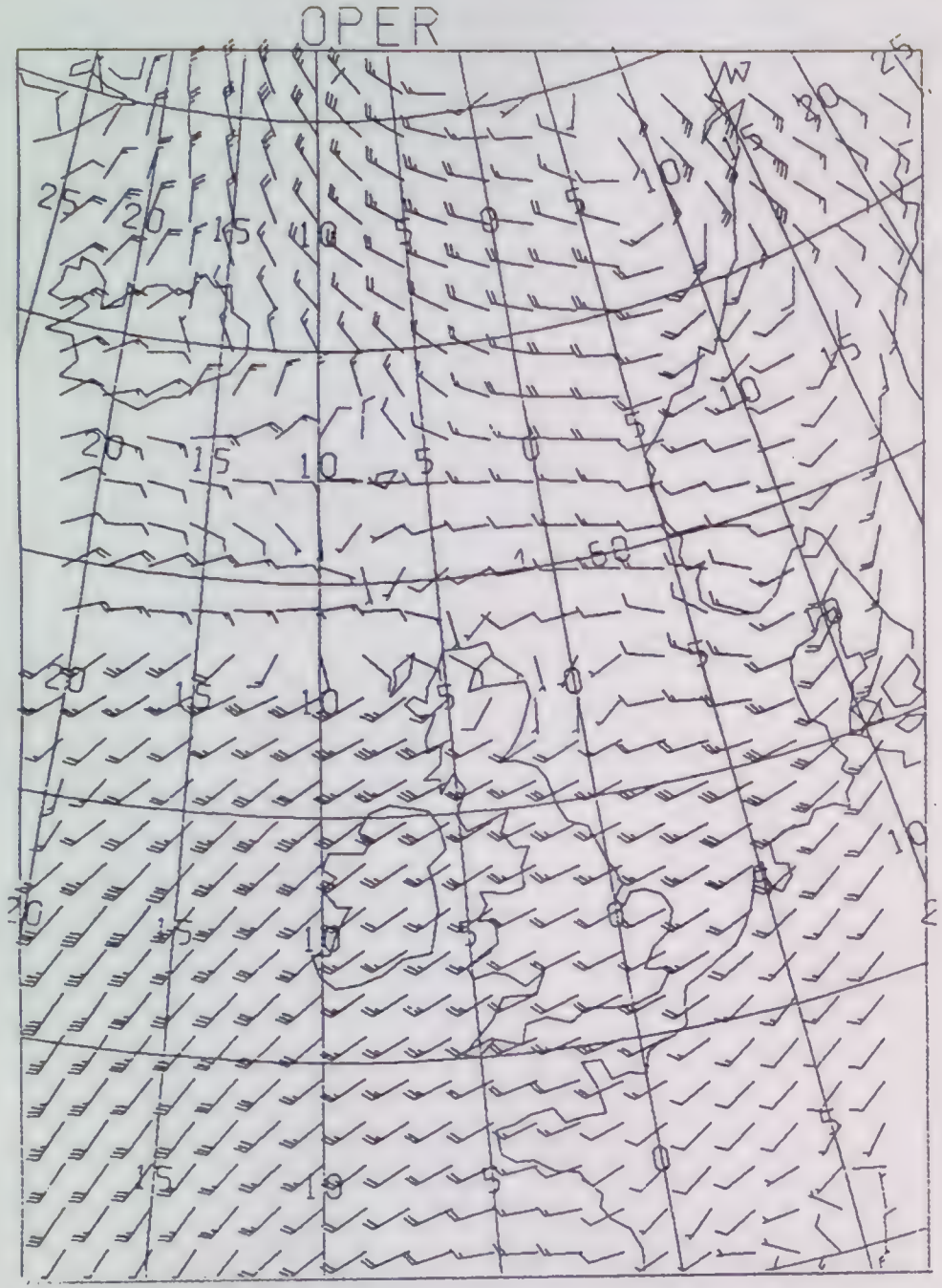


FIGURE 7.8(a)
10M WIND T+18 F/C DT00Z VT 18Z 10/12/94

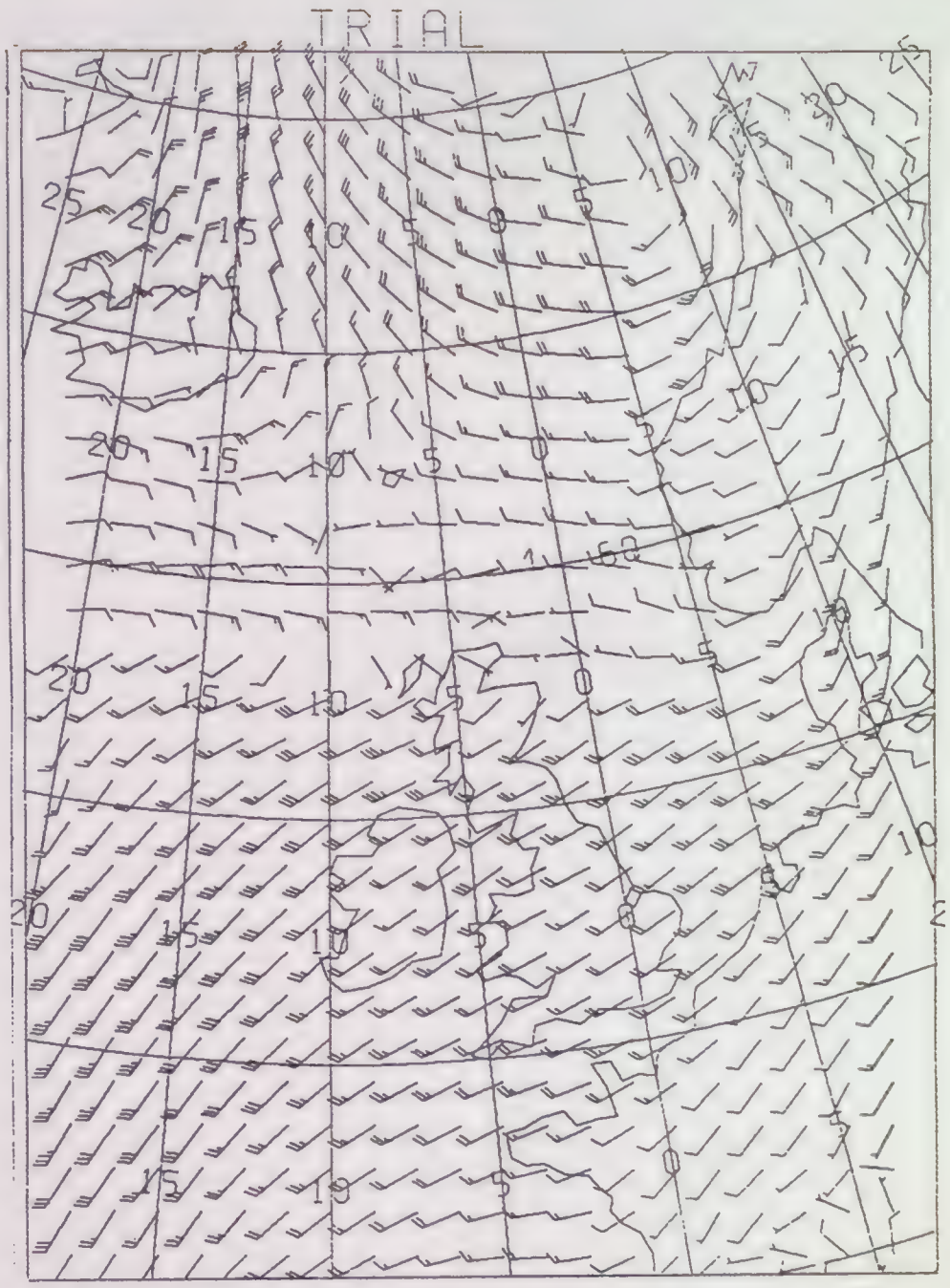


FIGURE 7.8(b)
10M WIND T+18 F/C DT00Z VT 18Z 10/12/94

FIGURE 7.9(a)
1.5M TEMPERATURE DIFFERENCES T+36
(MEANED OVER PERIOD 12Z 4/12/94-12Z 17/12/94)
OPERATIONAL - TRIAL

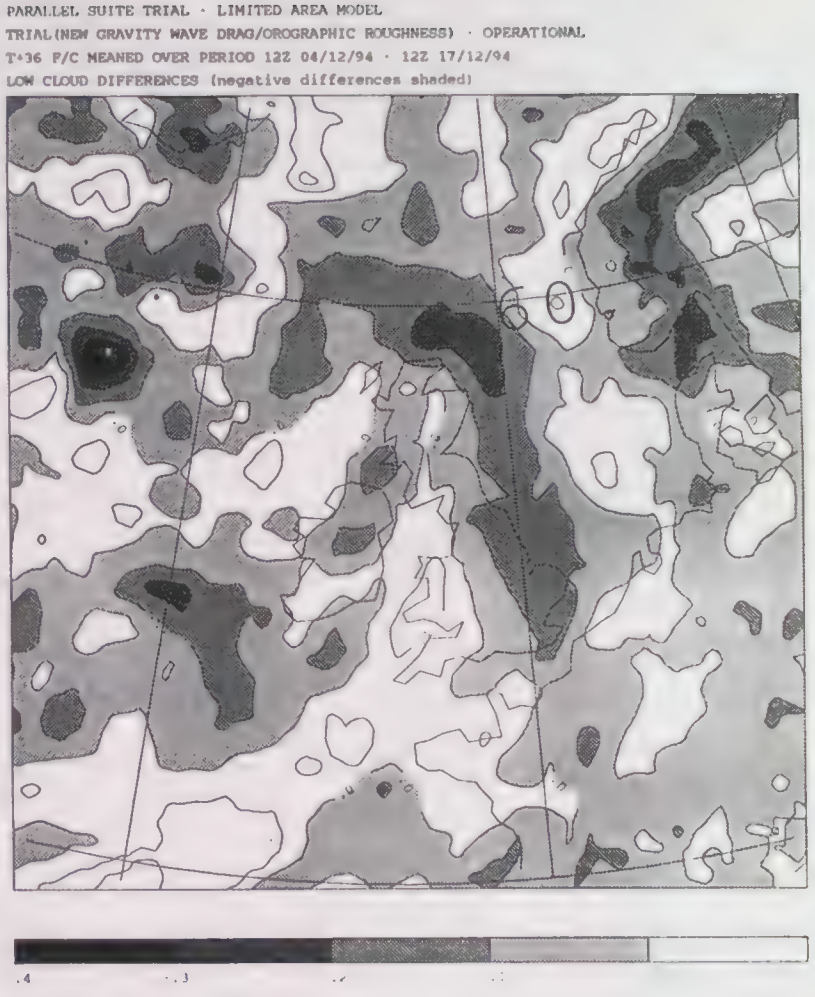
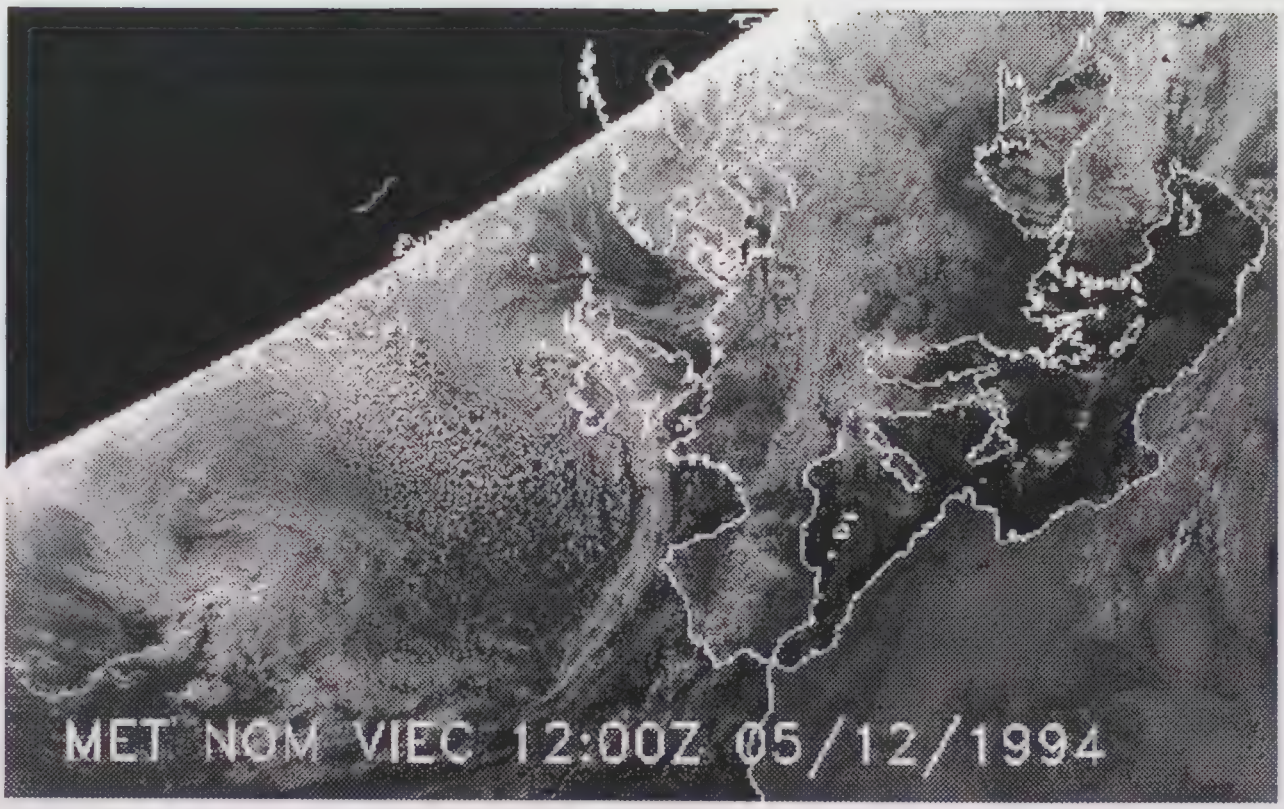
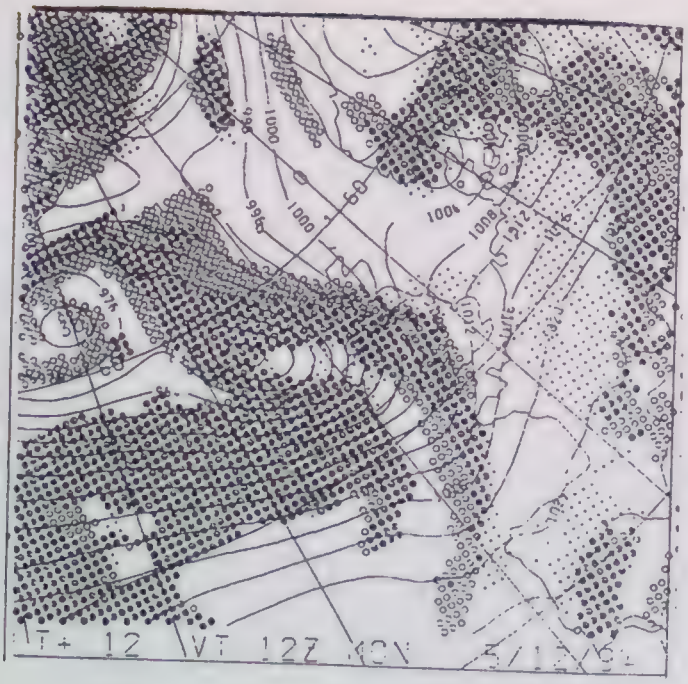


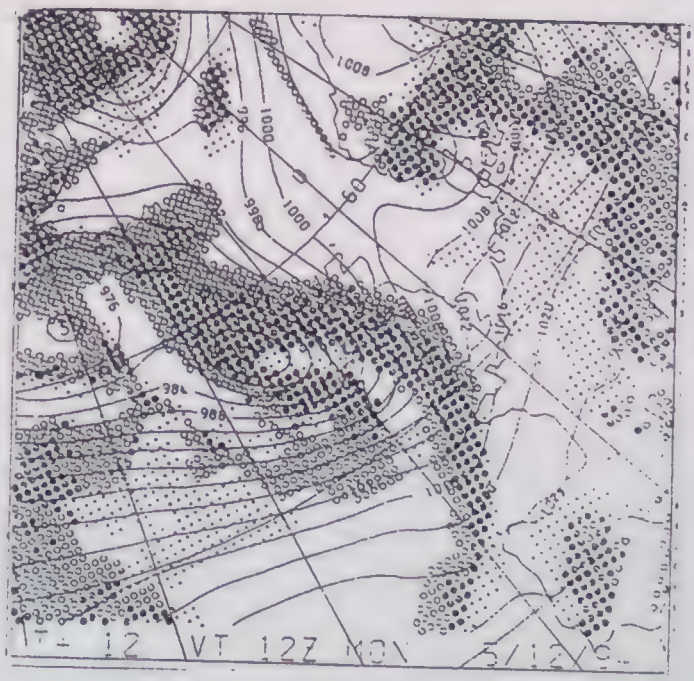
FIGURE 7.9(b)
LOW CLOUD DIFFERENCES T+36
(MEANED OVER PERIOD 12Z 4/12/94-12Z 17/12/94)
TRIAL - OPERATIONAL



(a)

(b)





(c)

FIGURE 7.10
(a) METEOSAT VISUAL SATELLITE IMAGE FOR 12Z 05/12/94
(b) OPERATIONAL CLOUD T+12 F/C DT00Z 5/12/94 VT 12Z 5/12/94
(c) TRIAL CLOUD T+12 F/C DT00Z 5/12/94 VT 12Z 5/12/94
o=>4 octas medium cloud .=>4 octas low cloud

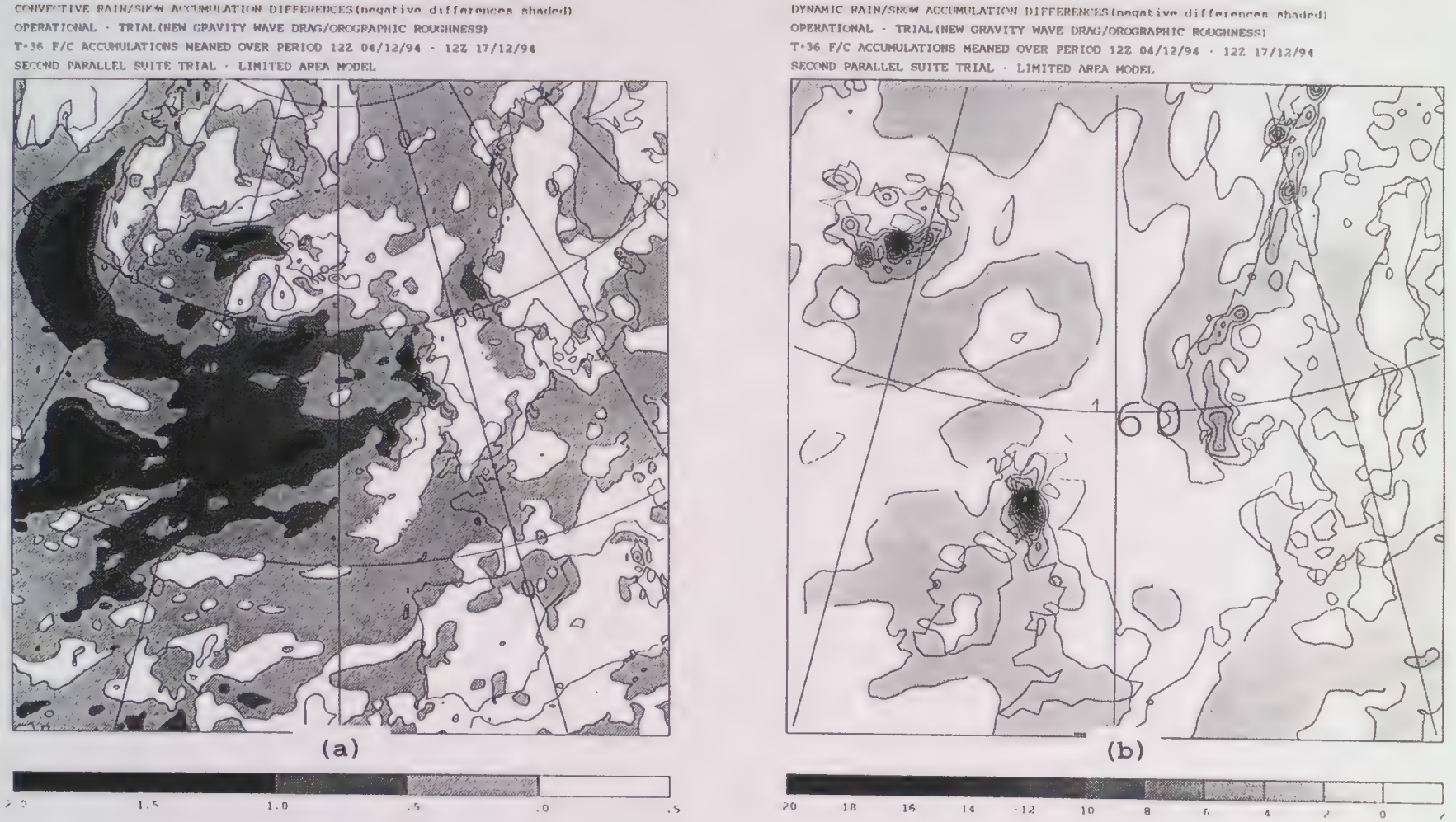
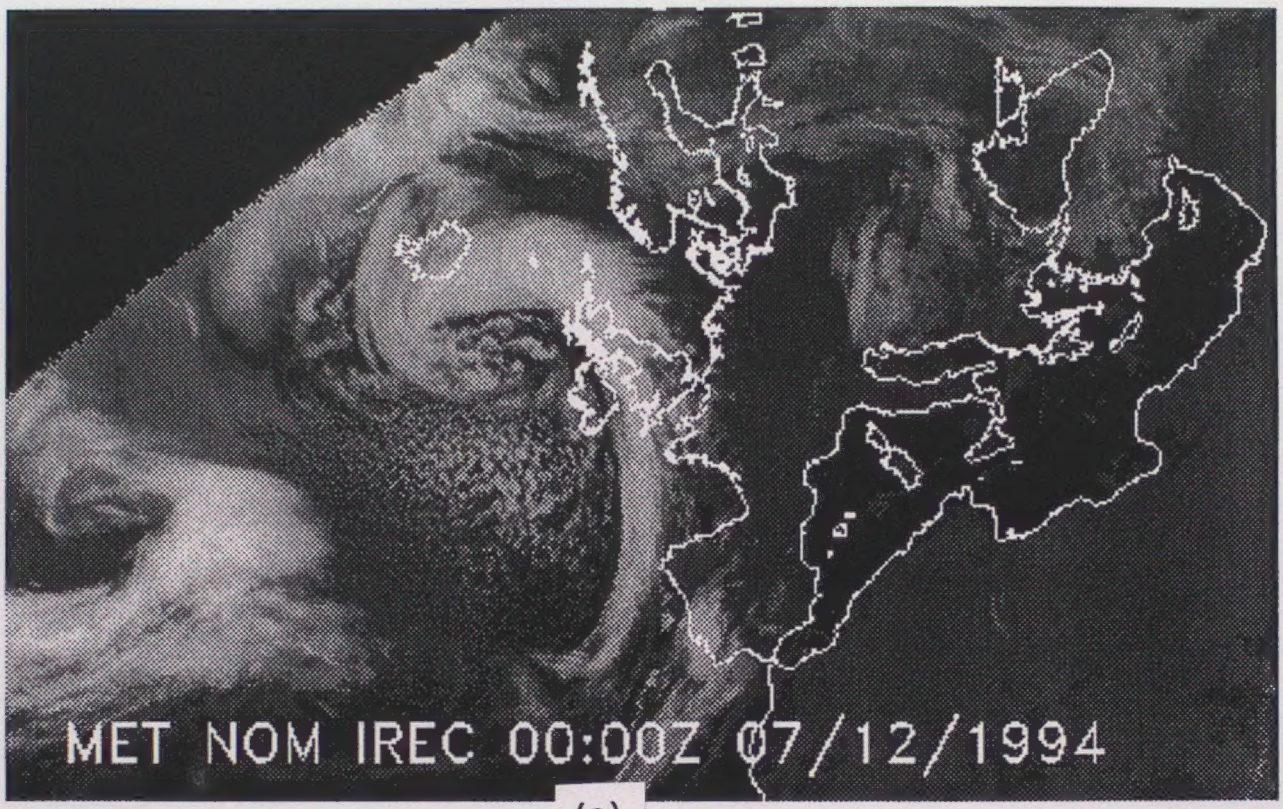
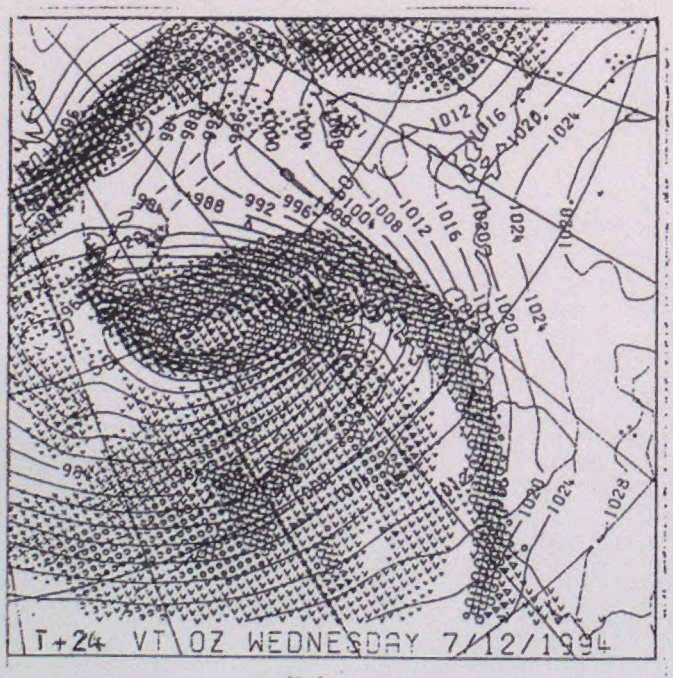


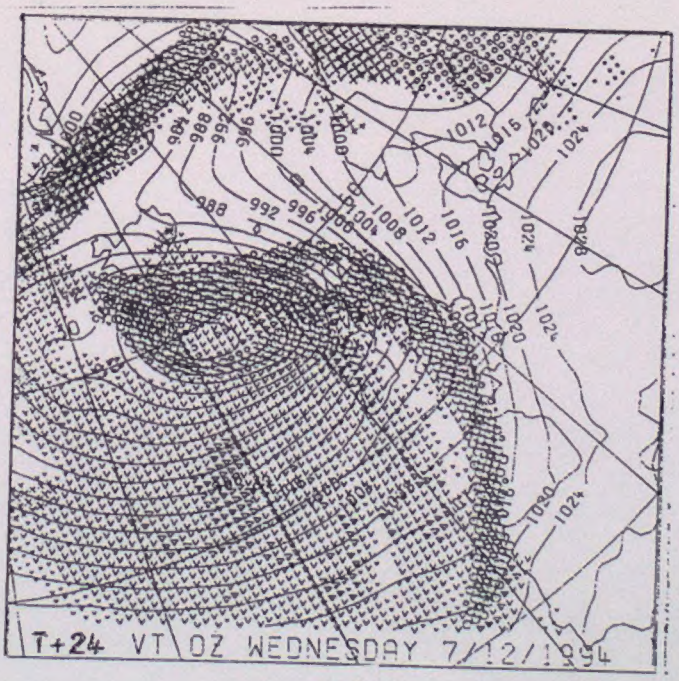
FIGURE 7.11
MEAN PRECIPITATION DIFFERENCES T+36 ACCUMULATIONS
OPERATIONAL - TRIAL(NEGATIVE DIFFERENCES SHADED)
MEANED OVER PERIOD 12Z 4/12/94 - 12Z 17/12/94
(a) CONVECTIVE RAIN/SNOW
(b) DYNAMIC RAIN/SNOW



(a)

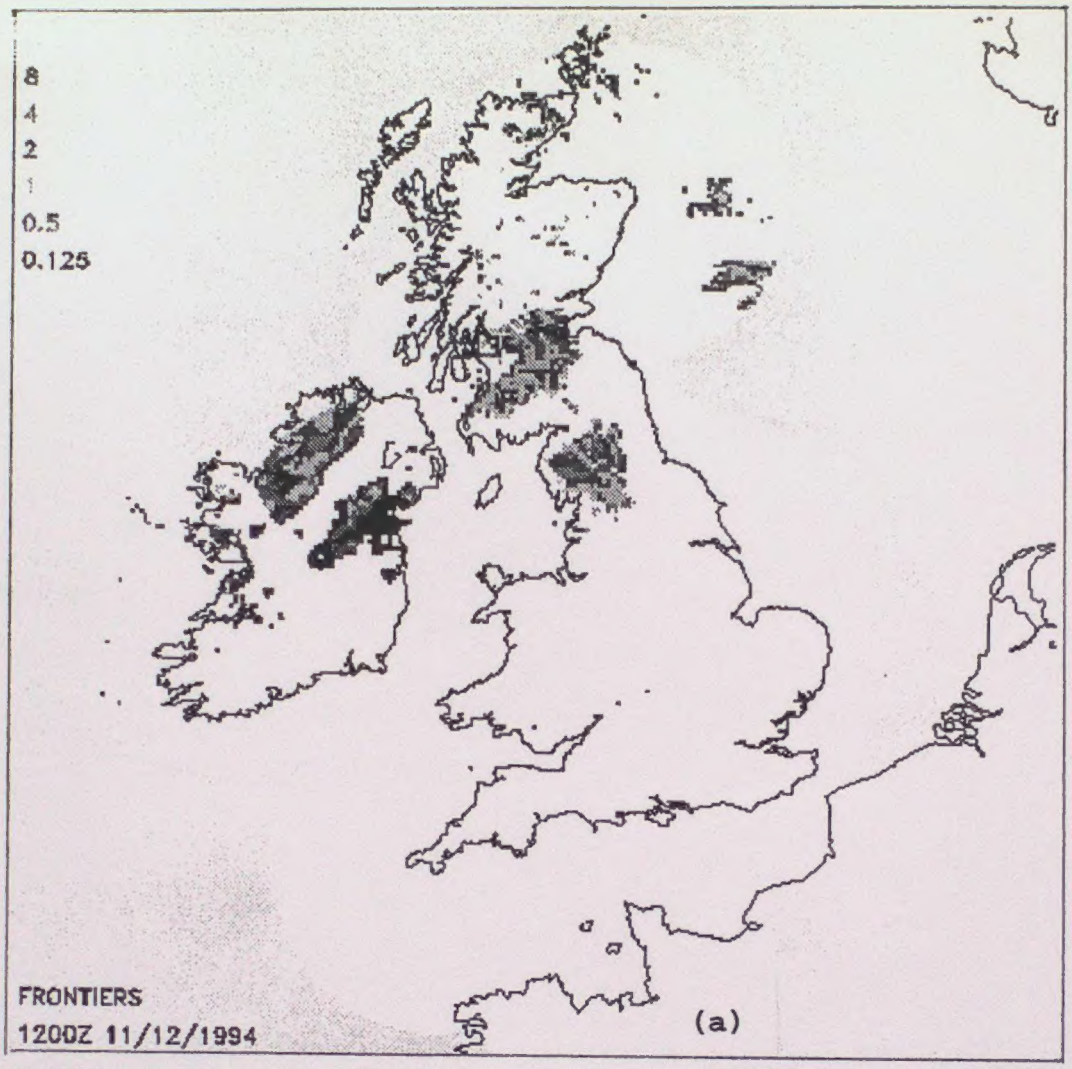


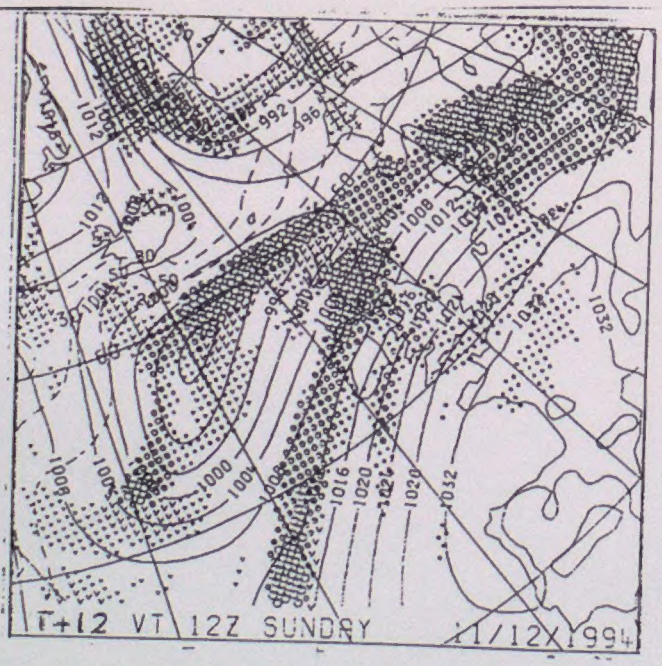
(b)



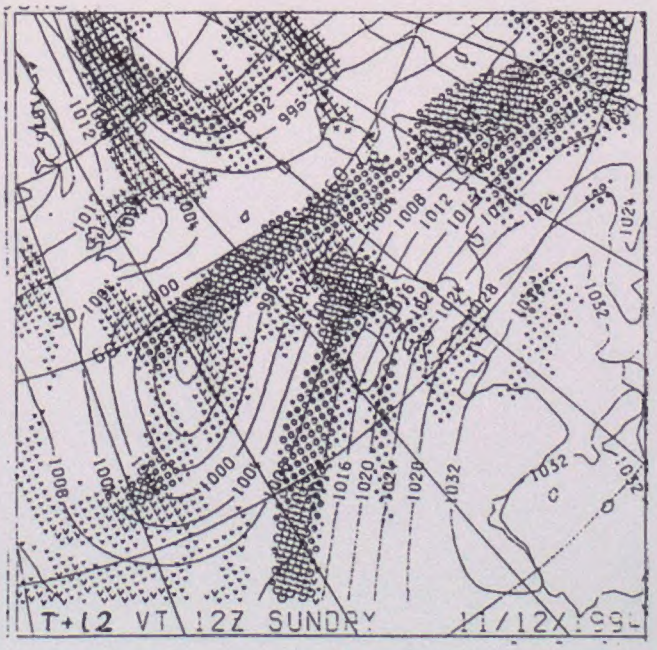
(c)

FIGURE 7.12
(a) METEOSAT INFRA-RED SATELLITE IMAGE FOR 00Z 7/12/94
(b) OPERATIONAL TOTAL RAINFALL RATE T+24 F/C
DT00Z 6/12/94 VT00Z 7/12/94
(c) TRIAL TOTAL RAINFALL RATE T+24 F/C
DT00Z 6/12/94 VT00Z 7/12/94



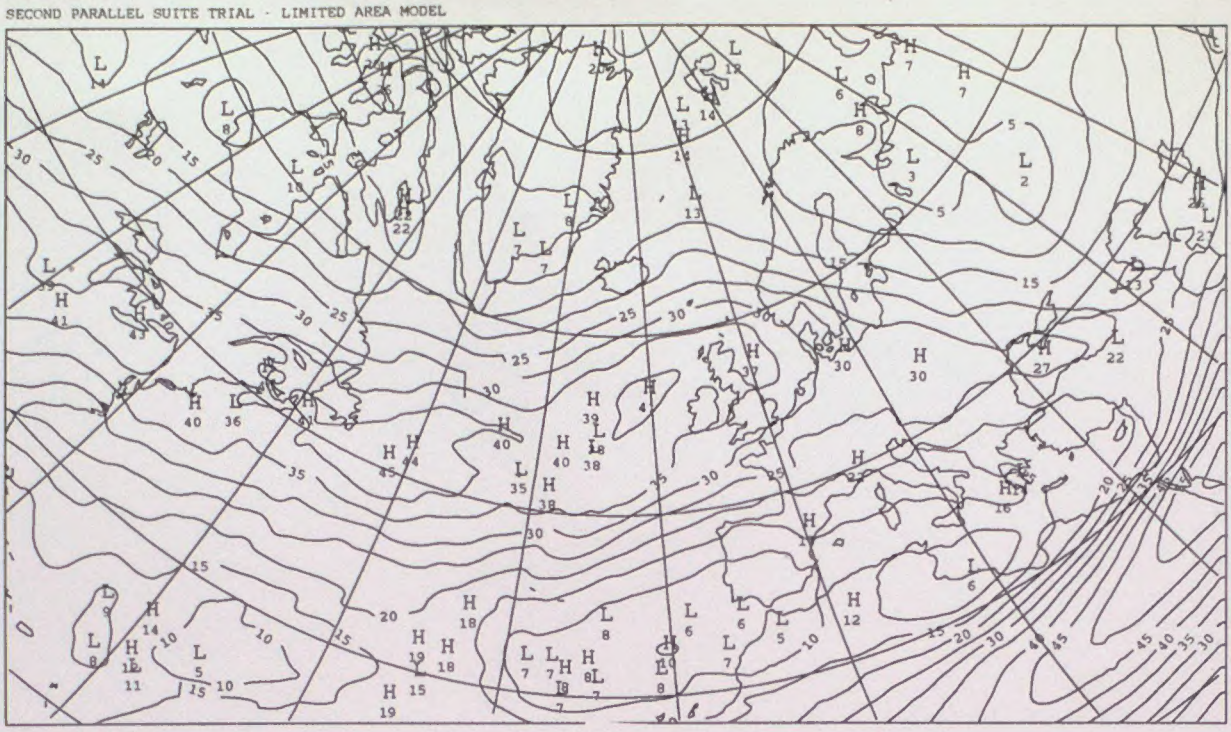


(b)

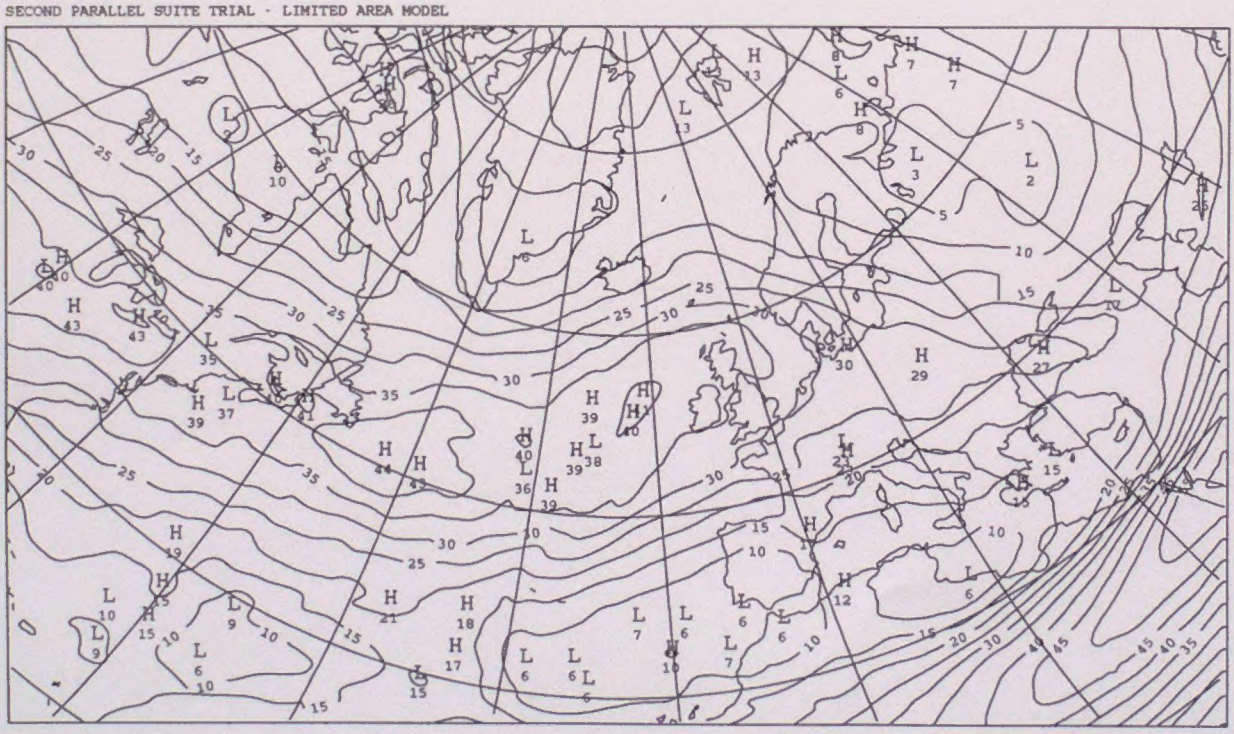


(c)

FIGURE 7.13
(a) RADAR IMAGE FOR 12Z 11/12/94
(b) OPERATIONAL TOTAL RAINFALL RATE T+12 F/C DT00Z 11/12/94 VT12Z 11/12/94
(c) TRIAL TOTAL RAINFALL RATE T+12 F/C DT00Z 11/12/94 VT12Z 11/12/94



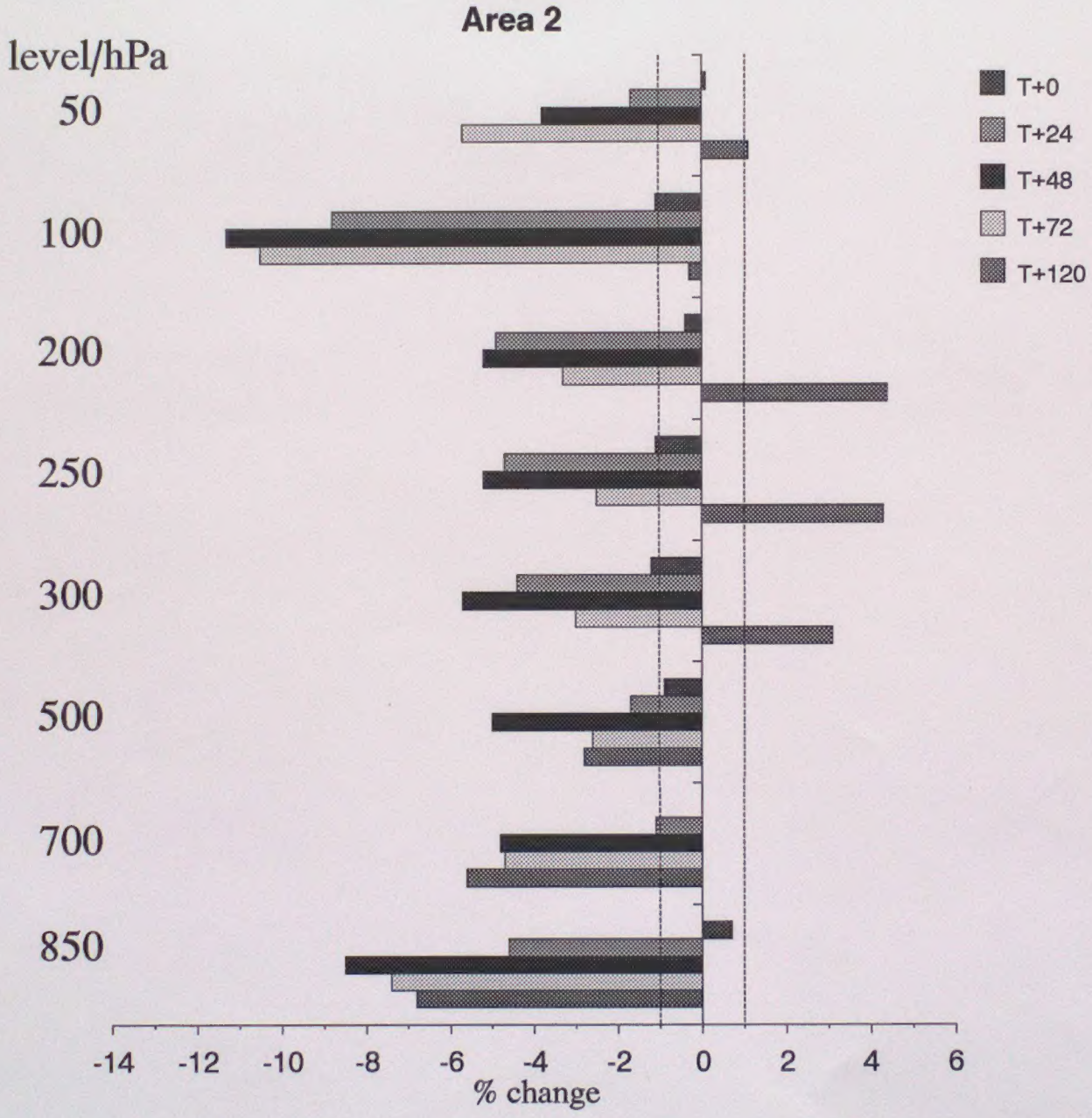
(a)



(b)

FIGURE 7.14
250HPA WIND ISOTACHS T+24 F/C
MEANED OVER PERIOD 12Z 04/12/94 - 12Z 17/12/94
(a) OPERATIONAL
(b) TRIAL

VERIFICATION AGAINST OBSERVATIONS
% Change RMS HEIGHT



2nd P Suite New GWD +Orog roughness
03/12/94-15/12/94